VISUAL OPTICS

AND

SIGHT TESTING

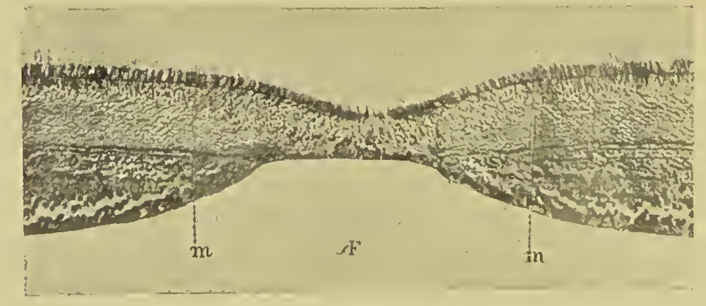
LIONEL LAURANCE


DOMINE
UT VIDEAM

W.L. Dixon

VISUAL OPTICS AND SIGHT TESTING

Photograph of the Fundus of a Normal Eye. (Magnified about 6 diameters.)
Enlarged 2 diameters from the original photograph taken from life by
Professor Dimmer, of Graz.



Vertical Section of the Macular Area.
From a photograph by Dr. Geo. Lindsay Johnson, showing—
F, The foveal pit ; *mm*, the true macula.

Frontispiece.

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VISUAL OPTICS AND SIGHT TESTING

BY

LIONEL LAURANCE

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CONTENTS

SYMBOLS AND ABBREVIATIONS

Em.	Emmetropia, or Emmetropic.
Am.	Ametropia, or Ametropic.
H.	Hypermetropia, or Hypermetropic.
Hl.	Hypermetropia latent.
Hm.	Hypermetropia manifest.
Ht.	Hypermetropia total.
M.	Myopia, or Myopic.
As.	Astigmatism, or Astigmatic.
M. As.	Myopic astigmatism.
H. As.	Hyperopic astigmatism.
Pr. or Pres.	Presbyopia, or Presbyopic.
Aniso.	Anisometropia, or Anisometropic.
Asth.	Asthenopia, or Asthenopic.
Crys.	Crystalline lens.
T.	Tension or hardness of the eyeball.
P. L.	Perception of light.
L. D.	Light difference.
L. M.	Light minimum.
V.	Visus, vision.
V. A.	Visual acuity.
R.	Right.
L.	Left.
Nl.	Nasal.
Tl.	Temporal.
Con. or C.	Convergence.
Ac. or A.	Accommodation.
P. P. or P.	Punctum proximum. Near point.
P. R. or R.	Punctum remotum, far point.
O. D. or R. E.	Oculus dexter, right eye.
O. S. or L. E.	Oculus sinister, left eye.
O. U. or B. E.	Oculi unā, both eyes.
∞	Infinity, a distance not less than 20 ft. or 6 m.

μ	The index of refraction.
F or P. F.	Principal focal distance or focus.
F_1 *and* F_2	Anterior and posterior focal distances or foci.
f_1 *and* f_2	Conjugate focal distances or foci.
O.	Object.
I.	Image.
+ *or Cx.*	Plus, convex.
− *or Cc.*	Minus, concave.
Hor. or H.	Horizontal.
Ver. or V.	Vertical.
Mer.	Meridian.
D.	Diopter.
M. A.	Metre angle.
°	Degree.
°*d.*	Degree of deviation.
Δ	Prism diopter.
S. or sph.	Spherical.
C. or cyl.	Cylindrical.
Pr.	Prism.
Ax.	Axis.
⊂	Combined with.
=	Equal to.
>	Greater than.
<	Less than.
Peris.	Periscopic.
Pcx.	Periscopic convex.
Pcc.	Periscopic concave.
Dcx.	Double convex.
Dcc.	Double concave.
℞	Recipe, prescription.
c̄	Cum, with.
Æt. or AE.	Ætatis, aged.
J.	Jaeger.
S.	Snellen.
P. D.	Pupillary distance.
Ht.	Height of bridge.
Proj.	Projection.

PREFACE

I HAVE embodied in this work all the matter contained in my small book "The Eye," and I have endeavoured to cover here and in "General and Practical Optics," all that is essential for the sight-testing optician. That I shall not have succeeded will be but natural.

Those who desire a higher knowledge of special subjects are recommended to study Dr. Lindsay Johnson's "Atlas of the Fundus Oculi," Dr. Maddox's works on prisms and the ocular muscles, Dr. Percival's on optics, Dr. Edridge Green's on colour vision and blindness, and Dr. Tscherning's on physiologic optics, while Dr. Hartridge's Refraction deals with the subject from the aspect of the medical refractionist.

In order to cover the important points connected with the subject dealt with, the whole of the text is, of necessity, exceedingly condensed. At the same time, I found it impossible to avoid a certain amount of repetition in order to lead up to, supplement, or maintain the sequence of the various subjects as treated, or to impress more forcibly the most essential facts.

No apologies are needed for mentioning some indications of pathological conditions, since a person with defective sight may go to the optician when he should go to the oculist.

I have to acknowledge my indebtedness to Dr. Lindsay Johnson for much information contained in the text.

Mr. H. Oscar Wood has aided and advised throughout in the compilation and arrangement of the work; with a few exceptions he has made all the drawings, worked up several of the collateral subjects, and generally revised the whole of the subject-matter. He has taken a large and active share in the work.

LIONEL LAURANCE.

ERRATA

Page 14, line 19, *for* "posterior" *read* "anterior."
,, 16, line 6, *for* "L′LF" *read* "L′NF."
,, 46, line 15, *for* "40 Cm." *read* "15 Cm."
,, 51, in description of diagram, *for* "CC' and BB'" *read* "ee' and bb'."
,, 65, line 5 from bottom, *for* "one eye" *read* "each eye."
,, 71, line 6, *for* "·00291" *read* "·000291."
,, 103, line 12, *read* "11·5 + ·531D′."
,, 128, line 9, *read* "will carry F_1 back to."
,, 153, line 21, *for* "or" *read* "to."
,, 165, line 12, *read* "+ prisms to decrease."
,, 205, lines 12 and 41, *read* "simulating" and "simulates."
,, 239, line 8, *for* "in" *read* "on."
,, 254, line 3 from bottom, *for* "No. 4" *read* "No. 6."
,, 269, line 12, *for* "nasal" *read* "temporal."
,, 275, line 6, *for* "subject" *read* "object."
,, 306, line 14, *for* "as" read "of."
,, 329, line 11, *for* "25" *read* "2·5."
,, 345, last line, *for* "smaller than" *read* "same as."
,, 357, line 18, *for* "T" *read* "T_C."
,, 362, line 5, *read* "$F_1 = \frac{FF_1'}{F} = F_1'$."
,, 362, line 6, *read* "$F_2 = \frac{FF_2'}{F} = F_2'$."
,, 362, line 12, *for* "E_2 coincides" *read* "E_1 coincides."
,, 365, line 10, *read* "$\frac{D_1}{\mu_2} + \frac{D_2}{\mu_1} = D_P$."

Visual Optics and Sight Testing.

VISUAL OPTICS AND SIGHT TESTING

CHAPTER I

ELEMENTARY ANATOMY OF THE EYE

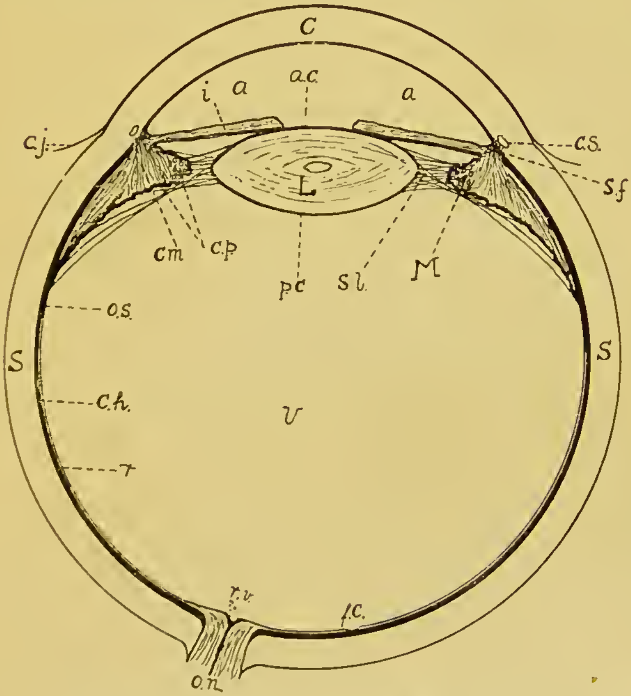


Fig. 1.—Horizontal Section of the Eye (Diagrammatic).

a, Aqueous; *v*, vitreous; *L*, crystalline; *C*, cornea; *S*, sclerotic; *ch*, choroid; *r*, retina; *cm*, ciliary muscle; *cp*, ciliary processes; *M*, Müller's ring; *fc*, fovea centralis; *i*, iris; *sl*, suspensory ligament; *sf*, spaces of Fontana and pectinate ligament; *cs*, canal of Schlemm; *ac*, anterior capsule of lens; *pc*, posterior capsule of lens; *cj*, conjunctiva; *on*, optic nerve; *os*, ora serrata; *rv*, entrance of retinal vessels.

The Eyeball is an elastic body, about 1 inch in diameter, approximately spherical, and having the segment of a smaller sphere projecting from the front. There are three coats which surround and enclose three transparent humours.

The First Coat consists of the *sclerotic* and *cornea*, their junction being termed the sclero-corneal margin.

The Sclerotic is a tough, opaque, fibrous membrane which surrounds about five-sixths of the globe. It is about 1 mm. thick at the back, thins slightly towards the equator, to again become somewhat thicker at its junction with the cornea. The sclerotic may be regarded as the wall or protective envelope of the eye, its functions being to preserve the contents from injury and to maintain its shape. Its colour is milk-white, but, if thin, has a bluish tinge, and if pigmentation is heavy, as in negroes, it is yellowish.

The Cornea projects from the front of the sclerotic, and covers the remaining one-sixth of the globe; its tissue is elastic and transparent, and it may be regarded as the window of the eye, through which the light is admitted. The cornea, with the aqueous, forms the first and principal refracting medium in the dioptric system and the two resemble a segment of a sphere of transparent celluloid. The diameter of the cornea is 12 or 13 mm., and its average thickness 1 mm., but it is rather thinner at the apex than at the scleral margin. The radius of curvature of the anterior surface is about 8 mm., that of its posterior surface about 6·5 mm., so that the cornea forms a concave meniscus whose index of refraction is taken to be 1·33. The cornea of an infant does not differ much in general dimensions from that of an adult.

The cornea has three layers—

1. The *outer*, or *epithelial*, which is continuous with the epithelial layer of the conjunctiva.

2. The *middle*, or *true corneal*, which occupies the greater part of the corneal thickness.

3. The *internal*, or *membrane of Descemet*, which is a highly elastic layer lined internally by cells continuous with those on the front surface of the iris.

An incomplete transparent membrane (Bowman's) lies between Nos. 1 and 2.

The cornea has no bloodvessels in its substance, but is nourished by lymph flowing between the laminæ of the middle layer. It is richly supplied with fine nerve endings, which render it highly sensitive to touch and foreign bodies.

The Second Coat consists of the *choroid proper*, the *ciliary body*, and the *iris*.

The Choroid is composed of connective tissue, bloodvessels, and dark brown pigment cells; the processes of the latter, in the presence of light, elongate and contract, and are evidently connected with vision since they exist, to a greater or lesser degree, in all animals which have light-perceiving organs. The chief function of the choroid is probably *nutritive*, supplying, together with the ciliary body, nourishment for the whole of the eyeball.

The Ciliary Body is composed of the *muscle,* the *processes,* and the *suspensory ligament.*

The Ciliary Muscle consists mainly of two parts, *i.e.*, the *radiator,* which arises from the sclero-corneal margin and, passing backwards, is inserted into the choroid, and the *sphincter* (Müller's ring), whose fibres are at right angles to those of the radiator; these form a ring round the periphery of the lens about 1 mm. beyond its edge. The ciliary muscle lies between the ciliary processes and the sclerotic, and immediately behind the base of the iris.

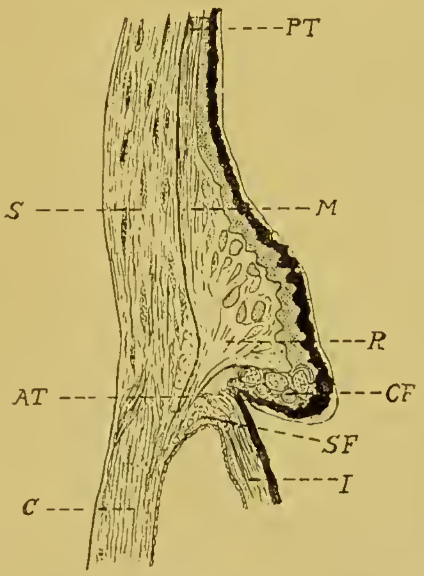


Fig. 2.—The Ciliary Body.

S, Sclerotic; *C*, cornea; *I*, iris; *SF*, spaces of Fontana; *AT*, anterior tendon of the ciliary muscle; *CF*, circular fibres; *R*, radiating fibres; *M*, meridional fibres; *PT*, posterior tendon of muscle.

The Ciliary Processes are a direct prolongation of the choroid, forming a convoluted gland, richly supplied with bloodvessels, and covered with secreting cells and dense black pigment. The function of these cells is to secrete a fluid to nourish the crystalline and vitreous humour, and to replenish the aqueous.

The Suspensory Ligament, or zonule of Zinn, consists of filaments arising from the membrana limitans interna at the ora serrata and from the ciliary processes. They are attached to the capsule of the crystalline at its periphery both in front and behind, and the triangular space thus formed at the margin of the crystalline by the suspensory ligament is called the *canal of Petit.* The ligament is not a complete membrane and the aqueous percolates through its filaments.

The Iris is a thin, highly pigmented membrane, having a central round aperture called the pupil, through which light enters the eye, the anterior surface being visible through the cornea behind which it lies and from which it is separated by the aqueous humour. The pupillary margin lies against the front surface of the crystalline, and is supported by the latter. On its anterior surface, up to the pupillary margin, there is a layer of cells continuous with those lining the posterior surface of the cornea. The posterior surface is thickly covered with black pigment cells continuous with those lining the ciliary processes. The quantity of pigmentation causes the iris to be light or dark, and gives to the eye its characteristic coloration.

The iris contains *straight* fibres, radiating from the centre, which dilate the pupil when the opposing circular fibres are inactive, the latter constituting a circular contractile muscular band, called the *sphincter pupillæ*, which surrounds the pupillary edge of the iris. The circular fibres are undoubtedly muscular, but the radiating fibres probably consist of elastic tissue kept slightly on the stretch by the sphincter. The diameter of the iris is about 12 mm., but that of the pupil varies, the average being, say, 3 or 4 mm.

The Retina, or third coat, consists of a network of fibres and cells in direct connection with the optic nerve and adapted to receive the impressions of light. It contains various layers, the most important being that of the *rods and cones* and the *hexagonal pigment-cell* layer, which secretes the visual purple, a substance intimately connected with vision. These two may be considered the receptive layers of the retina, since they are specially influenced by the action of incident light. The rods and cones are packed close together with their free ends touching the hexagonal pigment layer, and are turned away from the cornea (frontispiece), an arrangement apparently the most favourable for receiving the light stimulus, whether the latter be due to reflection from the choroid or to the conversion of the light energy into another form capable of transmission by the retinal and optic nerve fibres.

The retina is transparent and invisible in health, the red colour of the *fundus*, as the back of the interior of the eye is called, being due to the reflected light from the choroidal pigment and from the bloodvessels. Its thickness varies from 0·1 mm. to 0·3 mm. approximately, the average being 0·15 mm.

The Layers of the Retina and Choroid from the vitreous backwards are as follows:

1. *Internal limiting membrane.* A thin, almost structureless, membrane, whose inner surface lies in contact with the vitreous humour.

2. *Nerve-fibre layer.* A sheet of nerve fibres, which are the direct continuation of those of the optic nerve.

3. *Nerve-cell (ganglionic) layer.* The retinal bloodvessels, which are the branches of the central artery and vein, lie in this layer.

4. *Internal molecular layer.* A fine network of fibres, which shut off the large bloodvessels from the posterior layers.

5. *Internal granular layer.*

6. *External molecular layer.* Similar to No. 4. It shuts off communication with the capillaries.

6*a*. *The retinal plexus border layer.* A narrow, well-defined layer of fibres discovered in the retinæ of man and most monkeys, and so named by Lindsay Johnson. It is seen (frontispiece) in line with the front of the fovea, and extends only over and around the macular area.

7. *External granular layer.*

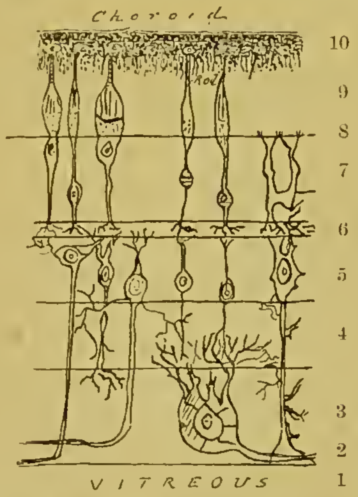


FIG. 3.—DRAWING MADE FROM A MICROSCOPIC SECTION OF THE RETINA.

1, Membrana limitans interna ; 2, nerve-fibre layer ; 3, layer of ganglion cells ; 4, internal molecular layer ; 5, internal nuclear layer ; 6, external molecular layer ; 7, external nuclear layer ; 8, membrana limitans externa ; 9, bacillary layer (rods and cones) ; 10, hexagonal pigment layer.

8. *External limiting membrane.* A thin, perforated membrane supporting and insulating the rods and cones.

9. *Bacillary layer, or layer of rods and cones.* The receptive terminals of the optic nerve, on the ends of which the image of an external object is supposed to be formed.

10. *Hexagonal pigment layer.* A glandular layer secreting the visual purple, in which the outer parts of the rods and the tips of the cones are embedded.

The layers of the choroid are—

11. *Limiting membrane (membrane of Bruch).* A transparent, colourless structureless layer.

12. *Layer of capillaries.*

13. *Layer of large bloodvessels.*

14. *External pigment (fusca) layer.*

Layers 1 and 8 are connected by vertical fibres which run at right angles to them, thus supporting the intermediate layers; 2, 3, and probably 5 and 7, form the conducting apparatus; 9 and 10 are receptive, while 10 has a secreting function as well.

The Macula and Fovea.—At the back of the eye in the line of the visual axis, about 1·25 mm. to the temporal side of the centre (posterior pole), is a highly sensitive area termed the *yellow spot*, or *macula lutea*. It is difficult to see with the ophthalmoscope, but may appear as a reflex ring surrounding a darker centre. The macular area, called the sensitive area, because all clear vision lies within it (frontispiece), is about 2·5 mm. in diameter, but the true macula is about 1 mm. in diameter, and is the area of most distinct vision. In its centre there is a minute pit, or depression, about 0·25 mm. in diameter, called from its position the *fovea centralis*, and this part consists entirely of narrow cone fibres packed closely together, where vision is most acute. The receptive faculty of the retina diminishes from the fovea to the ora serrata.

The Ora Serrata is the peripheral termination of the retina and lies a little anterior to the equator of the eye, near to where the choroid proper merges into the ciliary processes.

The Optic Nerve and Disc.—The *optic nerve* passes through the sclerotic at the back of the globe somewhat to the nasal side of the posterior pole. The head of the nerve, called the *optic disc*, can be seen with the ophthalmoscope (frontispiece), or in the eye when dissected, as a round or vertically oval, pinkish-white disc, from 2 to 2·5 mm. in diameter. The retina is absent at the disc, so that the latter is insensitive to light and is called the *blind spot*. The sheath of the optic nerve is continuous with the sclerotic. From the centre of the optic disc the retinal veins and arteries radiate over the fundus (frontispiece), and around the disc there may be often seen incomplete rings or crescents of white, bare sclerotic and of black choroidal pigment.

The Humours of the Eye.—The interior of the globe contains the crystalline lens which, with the ligament, separates the aqueous and vitreous humours, all three being transparent.

The Aqueous lies between the cornea and iris, and between the iris and crystalline lens, and is, as its name implies, a watery fluid, slightly saline, its index of refraction being 1·33. Its functions are to keep the cornea at its proper tension, to act as a lubricant to the iris, and to remove any waste products given off by the ciliary body and iris. It is constantly being renewed, and, if it escapes otherwise than naturally, is soon replaced. It is contained in a cavity about 2·6 mm. deep at the optic axis between the posterior surface of the cornea and anterior surface of the lens, and is about 12 mm. in diameter. The connective tissue at the angle of the chamber between the iris and cornea is called the *pectinate ligament,* which has coarse meshes—the *spaces of Fontana*—through which the aqueous and the waste secretions are carried off to the general circulation of the body. *The Canal of Schlemm,* whose function is somewhat uncertain, lies in close proximity to the pectinate ligament.

The iris divides the aqueous into two portions, an *anterior chamber,* above described, and a *posterior chamber* occupying the small triangular space between the iris and the periphery of the lens. Some anatomists, however, term the aqueous, as a whole, the *anterior,* and the vitreous the *posterior* chamber. The index of refraction of the aqueous is the same, for all practical purposes, as the cornea, with which it unites to form a single refracting surface.

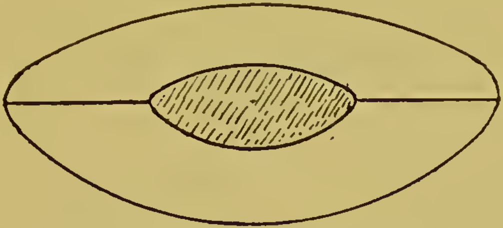


Fig. 4.—Diagram showing the Imaginary Component Parts of the Crystalline producing a Compound Lens.

The Crystalline lies immediately behind the iris and aqueous, and is embedded in a cup-like recess of the vitreous. It is contained in a capsule and retained in place by the *suspensory ligament* (zonule of Zinn) which is attached to its periphery. Its substance consists of series of fibres arranged in consecutive layers, as in an onion, and the junction of these fibres radiate from the centre to the circumference, resembling in front an inverted λ, and behind an upright Y. They are visible to the naked eye when the crystalline is removed, and are rendered very conspicuous by boiling. The crystalline is highly resilient, and can easily change its form, although with age this flexibility becomes, to a great extent, lost. When at rest it forms an unequally curved bi-convex lens about 8 mm. in diameter and 3·6 mm. thick at the centre, the radius of the front surface being 10 mm., and that of the back surface 6 mm. In childhood it is probably as thick as in adult life, but its diameter much less, so that the curvature of its surfaces is increased.

The nucleus is denser than the cortex, the index of refraction of the outer layers being but little higher than that of the aqueous—say 1·34—gradually increasing to the centre, where it is about 1·40, and the curvatures of the inner layers are greater than those of the periphery. The crystalline may be regarded as a small bi-convex lens of very high refracting power, having a series of convexo-concave shells in front and behind, or as a bi-convex lens enclosed between two convexo-concave menisci of lower power, as illustrated in Fig. 4.

The Vitreous Humour lies behind the crystalline and serves to preserve the tension and form of the globe, of whose volume it occupies about four-fifths. It is of a jelly-like nature, somewhat resembling the white of an egg, the outer surface, termed by some the *hyaloid membrane*, being bounded behind by the membrana interna, and in front by the ligament and lens capsule. Its depth, on the central line, is about 15 mm., and its width about 25 mm. Its index of refraction is the same as that of the aqueous, namely, 1·33, but unlike the aqueous, it cannot be replaced if allowed to escape.

The External Motor Muscles are six in number, and consist of the four *recti* and the two *obliques.*

The Four Recti arise from a tendinous ring at the apex of the orbit surrounding the optic foramen, and each is inserted, in front of the equator, into the sclerotic from 5 mm. to 8 mm. behind the corneal margin. The internal rectus is nearest the cornea, and then the inferior, external, and superior recti in that order. The superior and inferior recti are attached obliquely to the sclerotic, the nasal side of the attachment being nearer to the cornea.

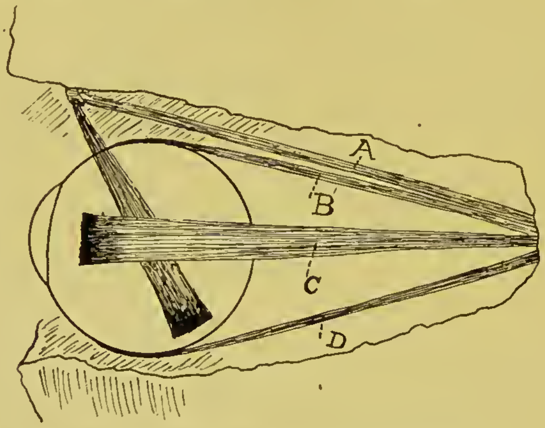


Fig. 5.—Diagram, from above, of the Motor Muscles of the Left Eye. *A*, Superior oblique ; *B*, internal rectus ; *C*, superior rectus ; *D*, external rectus. The inferior rectus and inferior oblique cannot be seen.

The Superior Oblique has the same origin as the recti, and, extending forward to the nasal angle of the orbit, passes through a small fibrous pulley—the *trochlea*—and then obliquely backwards and outwards beneath the superior rectus, to be inserted into the upper outer quadrant of the globe behind the equator. The effective origin of this muscle is its pulley. The **Inferior Oblique** arises from a depression at the nasal lower margin of the orbit and, winding round the globe beneath the inferior rectus, is inserted in the lower outer quadrant, some 6 mm. from the insertion of the superior oblique. The pulley of the superior oblique allows of increased length of muscle, and therefore of power and rapidity of action. The inferior oblique has little or no tendon, and, curling half round the globe, possesses great power and leverage for its size. The four recti are so termed because they run directly from their origin to their attachment to the sclerotic, while the obliques do not. The four recti, having their origin behind the globe, tend to retract the latter into its socket, while the obliques, having their origin in front, tend to advance it. Each muscle has a *check ligament*, which prevents excessive pressure on the globe, insures an even pull of the muscle, and tends to arrest retraction of the eye into the orbit.

The Ocular Appendages.—**The Orbit** is a funnel-shaped shell of bone having its wide opening towards the front; the eyeball is situated within it, and is there kept in position by the conjunctiva, Tenon's capsule, and the ocular muscles. The **Optic Foramen** is a small opening at the back of the orbit through which the optic nerve passes. **Tenon's Capsule** is an elastic conical sheath, divided into an anterior and posterior compartment, and filled with semi-liquid fat. It encloses the eye, which is hung within it, together with the muscles, bloodvessels, optic nerve, and lachrymal gland. At the back it is attached to the apex, and in the front to the outer rim, of the orbit, and gives off special sheaths for the optic nerve and each of the muscles. It has an outer fibrous and an inner mucous, or secreting, layer; a narrow space between the two communicates, through the optic foramen, with the brain.

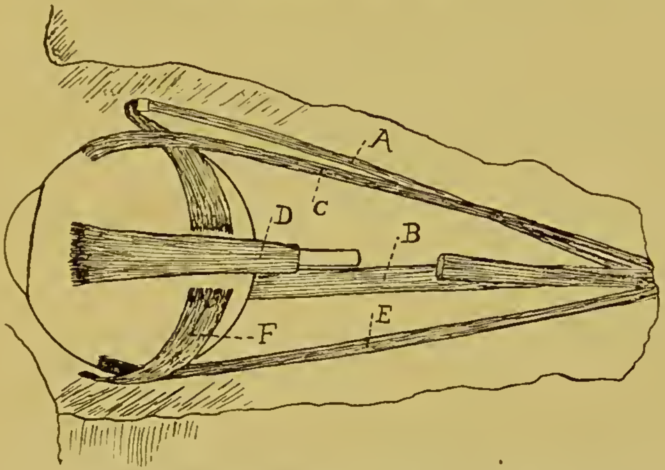


FIG. 6.—DIAGRAM, FROM SLIGHTLY BELOW ON THE TEMPORAL SIDE, OF THE MOTOR MUSCLES OF THE LEFT EYE, SHOWING THE INFERIOR RECTUS AND INFERIOR OBLIQUE.

A, Superior oblique; *B*, internal rectus; *C*, superior rectus; *D*, external rectus; *E*, inferior rectus; *F*, inferior oblique.

The Conjunctiva is a transparent membrane covering the inner surface of the lids and the front of the eyeball. Its functions are (*a*) to protect the eye, (*b*) to prevent foreign bodies from penetrating the orbit behind the globe, and (*c*) to reduce friction between the lids and the globe.

It consists of three parts :

1. **The Conjunctiva Tarsi**, a smooth membrane which lines the lid, and is firmly connected with the substance of the latter.

2. **The Conjunctival Fold**, continuous with and connecting 1 and 3, passes backwards, beyond the lids, in a loose fold which is reflected forwards upon itself to cover the globe. The fold above passes backwards farther than that below, and is called the *fornix conjunctivæ.* The looseness of the folds allows the globe to move freely in all directions.

3. **The Conjunctiva Bulbi** is that transparent portion which covers the visible part of the sclerotic, being prolonged over, and firmly attached to the cornea, forming its front layer. The corneal part of the conjunctiva is, in health, entirely free from bloodvessels, but the other portions are supplied with them.

The Caruncle is the small red glandular projection at the nasal angle of the commissure and is covered with a small free fold of conjunctival tissue, the *plica semilunaris*, which is the relic of the membrana nictitans, or third eyelid, common to a large number of mammals, birds, and reptiles. Occasionally it is more than usually developed in men and certain monkeys, but never so as to be functionally active.

The Eyelids consist of the external skin, a thick layer of dense connective tissue, termed the cartilage, and a thin muscular layer. At the free edge of the lids the skin passes abruptly into the mucous membrane lining the inside of each, and continuous with the conjunctiva. The upper lid serves as a kind of protector and to keep the anterior surface of the eye moist. The *Meibomian Glands* are situated beneath the conjunctiva, and their ducts lie along the free border of the lid, just internal to the lashes ; their function is to secrete an oily fluid to lubricate the inner surface of the lids and front of the globe. The opening between the lids is termed the *commissure ;* the outer and inner angles, formed by the lids at their junction, are respectively the *outer* and *inner canthus.*

The Muscles of the Lid are—

1. **The Levator Palpebræ**, which raises the upper lid.

2. **The Orbicularis**, forming a thin layer of fibres which surround the orbit, for a considerable distance. By its contraction the lids are closed and the skin round the eye drawn together, as in the act of winking.

The Lachrymal Apparatus consists of a gland, two puncta, two small canals, a sac, and a duct. The gland, which secretes the lachrymal moisture, is situated above the outer angle of the lids in a depression underneath the orbit and behind its rim. The secretion is carried by the movement of the upper lid over the front of the eye, but always towards the inner canthus, where it collects in the small cavity near the caruncle; it is then drawn through a minute opening—the *punctum*—in each lid into the lachrymal canal leading to the lachrymal sac, and thence, through the nasal duct, into the cavity of the nose, where it is evaporated or passes into the throat. All parts of the lachrymal apparatus are hidden from view, but the puncta can be seen as two minute perforations on the nasal edge of the upper and lower lids. The normal action of the lachrymal secretion is to bathe and keep clear the front of the eye, dust, etc., being carried by it over towards the inner canthus whence it can be easily removed. An excessive secretion of moisture, greater than can be conducted away by the puncta, becomes a flow of tears. The lachrymal secretion has the same refractive index as that of the cornea and aqueous, the confusion of vision caused by tears being due to the altered and unequal effect of the anterior surface of the cornea when the lachrymal secretion is excessive and irregularly distributed.

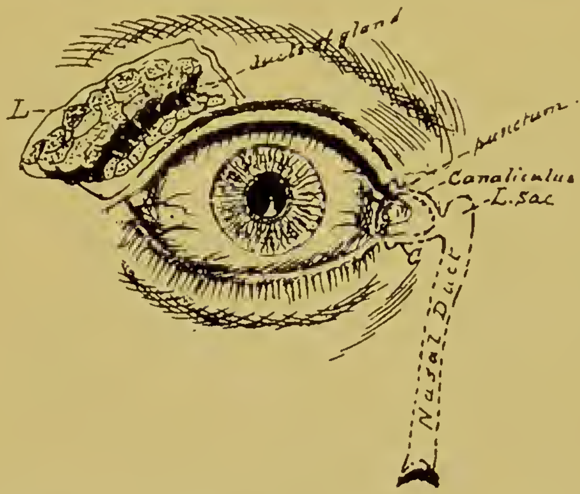


Fig. 7.—Diagram showing the Lachrymal Apparatus.

The Eyebrows consist of stiff hairs lying horizontally, and help to shade the eyes and to protect them from moisture falling from the forehead. The **Eyelashes** are stiff hairs at the margins of the lids, and are more or less curved away from the commissure; they shade the eyes and protect them from foreign bodies. The eyelashes and lids are prevented from sticking by the oily secretions of the meibomian glands, and the overflow of the lachrymal secretion in ordinary circumstances is restrained by the same means. A lens, against which the lashes continually brush, soon becomes smeared and translucent.

TABLE OF MUSCLES CONNECTED WITH THE EYE.

Muscle.	Action.	Nerve-Supply.
External rectus	Rotation of the globe	Sixth (abducens)
Internal rectus		Third (motor oculi)
Superior rectus		Third (motor oculi)
Inferior rectus		Third (motor oculi)
Superior oblique		Fourth (pathetic)
Inferior oblique		Third (motor oculi)
Sphincter of ciliary	Accommodation ..	Third (motor oculi)
Radiator of ciliary		Third, or sympathetic
Sphincter of iris	Pupillary action ..	Third (motor oculi)
Dilator of iris		Third, or sympathetic
Levator palpebræ	Movements of the lids	Third (motor oculi)
Orbicularis		Seventh (facial)

CHAPTER II

PHYSIOLOGY OF VISION

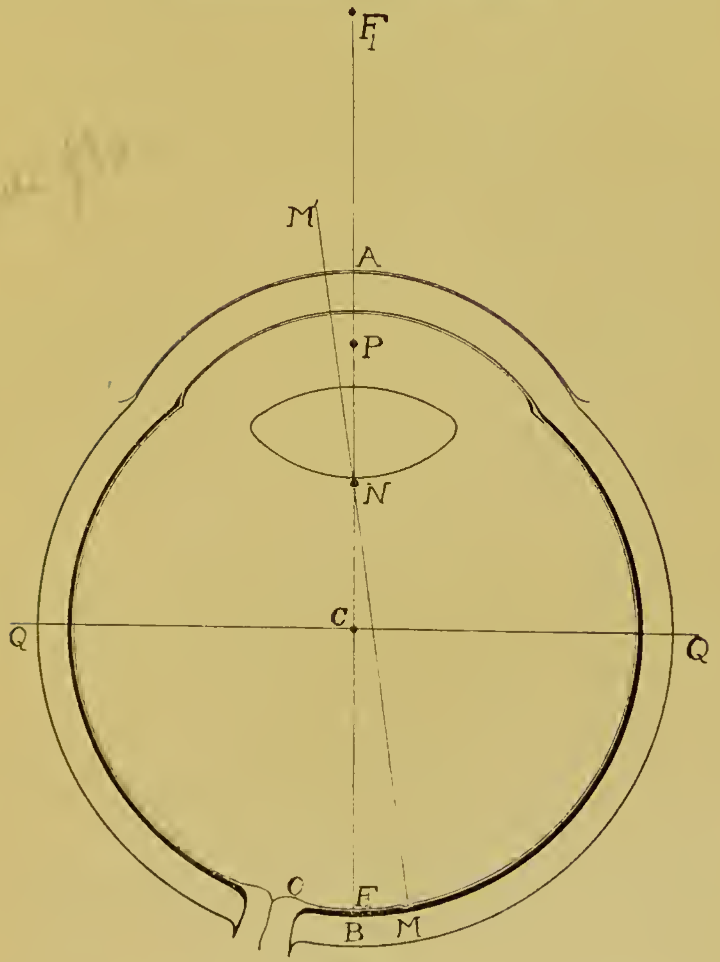


FIG. 8.—THE SCHEMATIC EYE.

O, The optic disc ; *M*, the macula ; *MM′*, the visual line ; *B*, the posterior pole ; *A*, the anterior pole ; *AB*, the optic axis ; *C*, the centre of rotation ; *N*, the nodal point ; *P*, the principal point ; *QQ*, the equator.

$PF_1 = 15$ mm. ; $PF_2 = 20$ mm. ; $PN = 5$ mm. ; $NF_1 = 20$ mm. ; $NF_2 = 15$ mm. ; $AP = 2{\cdot}2$ mm. ; $AN = 7{\cdot}2$ mm. ; $AB = 22{\cdot}2$ mm.

The Axis and Poles.—The optic axis is the central line of the globe, connecting the geometrical centre of the cornea with that of the fundus. It passes, therefore, through the centre of the crystalline to a point near the inner margin of the macula lutea. Where the optic axis passes through the centre of the cornea is *the anterior pole*, and the corresponding point at the centre of the fundus is *the posterior pole*.

The Equator and Meridians.—The *equator* is an imaginary plane vertical to the optic axis, dividing the eye into the *anterior* and *posterior hemispheres*. The various planes passing through the poles are called *meridians*.

The Nodal and Principal Points.—The optical centre of the eye is known as the *nodal point;* it lies on the optic axis, about 7·2 mm. behind the vertex of the cornea, and practically coincides with the posterior surface of the crystalline. The *principal point* marks on the optic axis the position of the imaginary plane in which the refraction of the various surfaces is presumed to be united; it is situated in the aqueous, about 2·2 mm. from the cornea, between the latter and the anterior surface of the crystalline. Actually there are two principal and two nodal points, but each pair is so close together that they may be considered one.

The Visual Axis, or line of vision, passes from the fovea through the nodal point to the point of fixation. It does not, therefore, coincide with the optic axis, but passes, with respect to the latter, upwards some 3° or 4° and inwards about 5°, piercing the cornea on the nasal side of the anterior ~~posterior~~ pole and slightly above it. When the visual axis is directed straight forward the resultant deviation of the optic axis is about 6° down and out in a plane inclined about 35° to the horizontal.

Fig. 9 represents the right eye, of which *Tl* is the temporal, and *Nl* the nasal side. *N* is the nodal and *P* the principal point, *C* the centre of rotation, *M* the fovea centralis, *A* the anterior, and *B* the posterior pole, *AB* the optic, and *MF* the visual axis. The point *C*, around which the eye revolves in its various excursions, is the *centre of rotation*.

The Corneal Axis *NE* is a line coinciding with the long axis of the corneal ellipse; it is supposed to be directed somewhat towards the optic disc, and therefore cuts the cornea on the temporal side of *A*.

The Fixation Axis *CF* is the line connecting *C*, the centre of rotation, with the point of fixation, *F*.

The Pupillary Axis *L′L* is a line normal to the cornea and passing through the centre of the pupil.

Angle α (alpha) is the angle *DNF* formed by the optic and visual axes at *N*, the nodal point; its size varies with the distances *MB* and *MN*. If the distance *MB* be 1·25 mm. and that of *MN* be 15 mm., we get $\sin\alpha = MB/MN = 1{\cdot}25/15 = {\cdot}083 = \sin 5^\circ$. Angle α is, therefore, about 5° in an ordinary eye. If *MB* be taken as a fixed quantity, the value of α diminishes as *MN* is greater, and *vice versa*. Thus in hyperopia α is greater than 5°, and may be as large as, say, 8°, while in myopia it is smaller, being sometimes as low as 2° ; if B coincides with M the value of α is zero, and it is negative if B lies to temporal side of M. Extreme values of α may result from anatomical anomalies as to the position of the macula with respect to the posterior pole.

Most writers apply the term α as above defined. Donders presumed the cornea to be ellipsoidal in curvature, with its long axis coincident with the optic axis. Later it was thought that the corneal axis was as NE on the temporal side of AB, and some writers called ENF angle α and DNF angle β (beta), or something else ; still later the existence of an ellipsoidal axis as a general condition became extremely doubtful. Whether there is, or is not, normally a corneal axis distinct from the optic axis, the former is of little consequence, and can be disregarded or taken as coincident with BA, so that angle α is that formed by the visual axis and the optic or corneal axis indifferently.

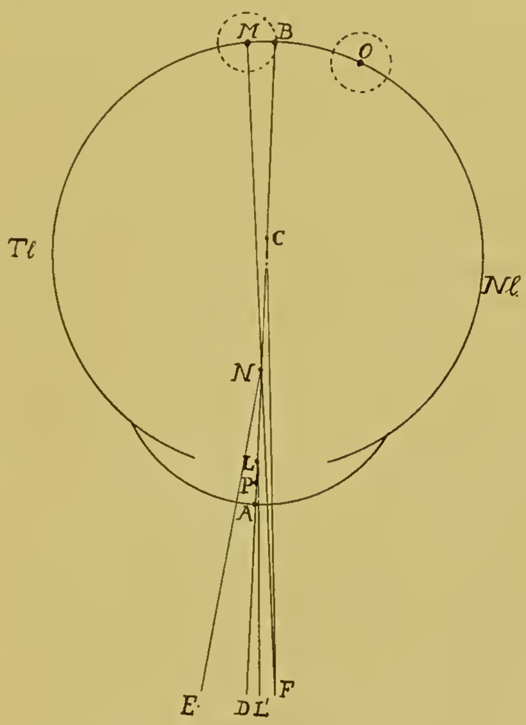


Fig. 9.

Angle γ (gamma) is that angle DCF formed at C, the centre of rotation, by the optic axis and the line of fixation. It can be seen that DCF differs but slightly from DNF, and the two may be taken as equal—in fact, it is very probable that the centre of rotation does not lie on the optic axis, and if it lies on the visual axis, the visual and fixation lines coincide.

It is very difficult to locate the anterior pole and optic axis. The centre of the pupil is to the nasal side of the centre of the cornea, and not immediately behind it; consequently, the image of a flame, seen in the centre of the pupil, is formed some 4 mm. behind the cornea, on a normal to it which passes through the centre of the pupil. Its direction does not, therefore, indicate *AB* but the line *LL′*.

Angle κ (kappa) is the angle *L′LF* formed by the central pupillary line and the visual or fixation line.

The corneal, optic, and pupillary lines may be regarded as the same, as may the visual and fixation lines. Therefore angles α, β, γ, and κ are, for all practical purposes, the same, and may be considered and called angle α. In practice the angle κ is the one usually measured.

M, the fovea centralis is, in the normal eye, 1·25 mm. distant from *B* on the temporal side, and the macular area being about 2·5 mm. in diameter, its nasal extremity coincides with *B*. The optic disc *O* is from 2·0 to 2·5 mm. in diameter, its temporal extremity being about 2·50 to 2·75 mm. to the nasal side of *B*. The disc varies in diameter, but the total distance between the centres of the disc and of the macula is approximately 2 discs' width. The fovea *M* lies rather below the centre of the disc and about 1 mm. below *B*. Fig. 9 represents, of course, a horizontal section of the eye.

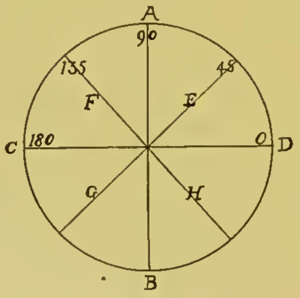


FIG. 10.

Quadrants and Meridians of the Eye.—*ACBD* is the cornea of a left eye, in which *AB* is the vertical and *CD* the horizontal meridians. *E* is the 1st, or upper temporal quadrant; *F* the 2nd, or upper nasal quadrant; *G* the 3rd, or lower nasal quadrant; *H* the 4th, or lower temporal quadrant.

The numbers given are the same for both eyes, but the temporal and nasal quadrants are reversed. Thus, in the left eye the 1st and 4th are temporal and the 2nd and 3rd are nasal, but, in the right eye, the 2nd and 3rd are temporal and the 1st and 4th are nasal. This numeration accords with the trigonometrical division of a circle in which the upper right quadrant is the 1st, and contains the angles between 0° and 90°; No. 2 contains the angles between 90° and 180°; No. 3 the angles between 180° and 270°, and No. 4 those between 270° and 360°. The *nomenclature* of the quadrants is anatomical, and therefore symmetrical as regards the median line of the face, but the *numeration* is not. It should also be observed that right and left differ in the mathematical and anatomical senses. Mathematically, the right or left of a body is that side opposite respectively the right or left hand of the observer, while anatomically the right or left is respectively on the right or left of the subject, and therefore contrary to the mathematical terms. In pure optics the mathematical nomenclature is used, but in visual optics the anatomical is adopted of necessity—*e.g.*, the right eye of a spectacle is for the right eye of the wearer. In all matters connected with the subject care must be taken not to confuse the terms.

The locus of the various meridians of the eye is of importance in sight-testing, and, as indicated, each eye is similarly divided into meridians, the notation of which commences at the right-hand extremity of the horizontal meridian as seen by the observer—that is, at the temporal extremity of the left, and the nasal extremity of the right, eye. This is more fully explained under "Astigmatism."

The Refraction of the Eye is obtained from the cornea, the aqueous, the crystalline lens, and the vitreous. Since the μ's of the aqueous and cornea may be taken as equal, as well as those of the aqueous and vitreous, the optical system of the eye resolves itself into a single refracting surface—*i.e.*, the front surface of the cornea, and a biconvex lens, the crystalline, the two components being separated by an interval. The refracting powers and focal lengths of the combined system are worked out in another chapter, and here it suffices to say that, in the optical system of the normal eye, termed the schematic eye, the anterior and posterior focal distances are measured from the principal point, *P* (Fig. 8). The first medium is air and the last vitreous, and, since their refractive indices differ, the anterior and posterior focal lengths also differ, F_1 being 15 mm. and F_2 20 mm. from *P*. For the same reason the refracting plane does not coincide with the combined optical centre, or nodal point, *N*, where the unrefracted secondary axes cut the principal axis. The distances of object and image from *N*, and not from *P*, govern the size of the real, inverted and reversed image formed on the retina by the dioptric system.

The Reduced Eye.—For the sake of simplicity the eye may be regarded as having only one refracting surface and one uniform medium of index 1·333. The crystalline and actual cornea are presumed to be removed, and the three refracting surfaces replaced by one whose centre of curvature is at *N*, the nodal point. Thus in the *reduced eye B*, shown in Fig. 11, the cornea occupies the position of, and replaces the refracting plane of, the schematic eye *A*, and all the cardinal points *P*, *N*, F_1 and F_2 are unchanged.

The Capacity of the Eye.—The eye, although only 1 inch in length, is capable of perceiving objects of every magnitude down to one of $\frac{1}{500}$ inch, or even less, with a range varying from a few inches to an infinitude of miles. The dioptric system is specially constructed for collecting and arranging light rays, so that they may impress the retina with a distinct image of the object seen. The eye performs the functions of a variety of optical instruments, being at the same time a microscope, a telescope, a telemeter, a cinematograph, and a panoramic camera. We see life-sized moving objects in natural colours and in stereoscopic relief. As a photographic camera, having an adjustable lens and iris diaphragm, the eye works at anything between F/11 and F/3, the focal-length of the lens system being, say, 20 mm., and the aperture of the iris 2 to 7 mm. in diameter. By means of the refracting media, a sharp picture of an object is formed on the retina, and by means of the accommodating power, objects at various distances can be distinctly seen without the necessity of approaching or moving away from them. By means of the external muscles, objects situated in various positions, in relation to the observer, can be viewed without movement of either the head or the object.

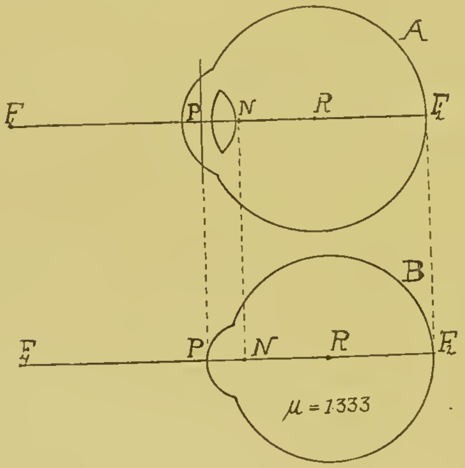


Fig. 11.—*A* is the Schematic and *B* the Reduced Eye.

The line F_1F_2, passing through *N* and *P*, is the optic axis; *N* is the nodal and *P* the principal point; F_1 and F_2 are the anterior and posterior principal foci.

The iris, and to some extent the lids, regulate the quantity of light admitted to the interior of the eye. The choroid and back of the iris absorb superfluous light, thus preventing internal reflection, and, when darkness is necessary, the light is shut out by the lids.

The Visual Angle is that subtended by the object at the nodal point. It can be constructed by drawing to the nodal point straight lines from the extremities of the object, and its size is directly proportional to that of the latter, and inversely as its distance. The larger the object and the shorter its distance, the larger is the visual angle, and *vice versa*. Both the object and its retinal image subtend equal angles at the nodal point, but, as in an ordinary camera, the image is inverted.

The Retinal Image.—The size of the image depends on the visual angle, so that we have this proportion: As the distance of object is to the size of object, so is 15 mm. to the size of the retinal image, where 15 mm. is the generally accepted distance from nodal point to retina. The size and distance of the object may be expressed in any terms, provided they are the same, and the size of the image is then in mm.; the distance of the object is taken to be from the nodal point of the eye. Thus, suppose an object 2 yards in diameter be situated 30 yards from the eye, then the size of the retinal image is—

$$I = \frac{2 \times 15}{30} = 1 \text{ mm.}$$

The size of the retinal image of a given object varies in different eyes, independently of the angle under which it is formed. It is governed by the distance between the nodal point and the retina—that is, it depends on the distance which the axial rays have diverged from each other, on departure from the nodal point, when they reach the fundus. The retina is further from the nodal point in M., and nearer in H., so that the myope sees things relatively large and the hypermetrope relatively small (vide Chap. XX.). In the calculation for the retinal image in a myopic or hypermetropic eye a greater or smaller value, therefore, must be taken for the distance between the nodal point and retina. Thus, for the same size and distance of the object as in the example given, if the distance between the nodal point and the retina were 13 mm.—

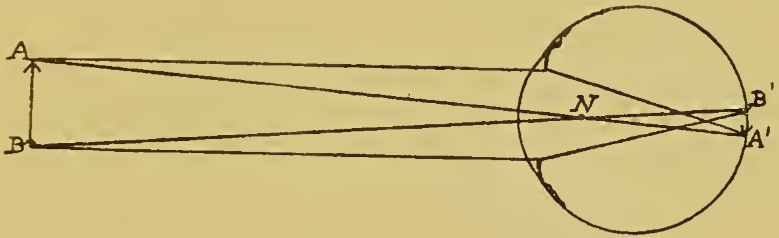


Fig. 12.—Showing Construction of the Retinal Image.

AB is the object, and *B'A'* the inverted retinal image. *N* is nodal point, and *ANB* = *B'NA'* is the visual angle.

$$I = \frac{2 \times 13}{30} = \cdot 866 \text{ mm.}$$

Visual Requisites.—The requisites for clear vision are transparency of the media, receptive faculty of the retina, transmissive faculty of the optic nerve, and perceptive or psychic faculty of the brain. In addition, there are three others with which the optician is more closely concerned, namely—

Refraction, or the power of the eye to bring light diverging from distant objects to a focus at the retina.

Accommodation, or the auxiliary refracting power of the eye required for bringing light diverging from near objects to a focus at the retina.

Convergence, or the action of the internal recti, by means of which the visual axes are directed to the same object, so that single vision may obtain over a large range of distance.

Static and Dynamic Refraction.—The *static* refraction is that of the whole eye when accommodation is at rest. The *dynamic* refraction is that derived from accommodation. The two combined constitute the *total* refracting power of the eye—*i.e.*, total = static + dynamic.

Accommodation.—In order that the eye may have a sharp retinal image for varying distances of the object viewed, it must possess some means of counteracting the change in the distance of the image caused by the change in the divergence of the incident light. This power is termed *accommodation*, and can be brought about theoretically in three ways :

1. By increase and decrease in curvature of the crystalline lens.
2. By increase and decrease in the curvature of the cornea.
3. By elongation and shortening of the globe, as in a camera.

Other theories, such as advance of the crystalline, contraction of the pupil, astigmatic refraction, and pressure of the ciliary body and the iris on the crystalline have been formulated, but all, except No. 1, have been disproved. The keratometer shows that there is no change in the size or position of corneal images during accommodation. No. 3 probably originated in the discovery that myopia was due to increased length of the globe. Accommodation cannot be caused by an advance of the crystalline as a whole, since the utmost possible movement towards the cornea would not result in anything like the increase of power equal to the average amplitude ; also the posterior surface of the lens is known to be in firm contact with the vitreous under all conditions. Contraction of the pupil is not sufficient to reduce the circles of confusion to anything approaching point foci, and accommodative effort is unaffected in aniridia (absence of the iris) and iridectomies.

There is only one accepted theory of Ac., namely, change of curvature of the crystalline lens. This has been proved by the experiments of Helmholtz, Cramer, Purkinje, Tscherning, and others. It was observed that the catoptric images formed by reflection from the surfaces of the crystalline underwent changes both as to position and size when Ac. was brought into play. These changes, almost entirely confined to the anterior surface, conclusively prove that an alteration in curvature takes place, and no other proof than this is really necessary. However, we also know that in aphakia complete loss of accommodative power accompanies loss of the crystalline.

It being recognized that Ac. does result from change in curvature of the crystalline lens, there have been several theories advanced as to how this change takes place, the two principal theories being those of Helmholtz and Tscherning. The theory of Helmholtz is now generally accepted, but that of Tscherning seems better to account for the distinct sense of effort which results in sustained Ac., Ac. for the P.P., and in presbyopia. Possibly what really does occur to the crystalline when Ac. takes place remains to be discovered.

Helmholtz Theory.—According to Helmholtz, the crystalline lens, with the eye in a state of rest, is flattened to its minimum curvature by the constant traction of the ligament, whose natural condition is one of tension. During accommodation, Müller's ring and the ciliary muscle, which is firmly attached to the sclero-corneal margin, contract and draw forward the processes and the periphery of the choroid with which the suspensory ligament is connected. The latter, therefore, relaxes its tension on the anterior capsule, and the lens, by reason of its own resiliency, bulges forward. On relaxation of accommodation the ligament returns to its original state of tension, and the lens is again compressed to its minimum curvature.

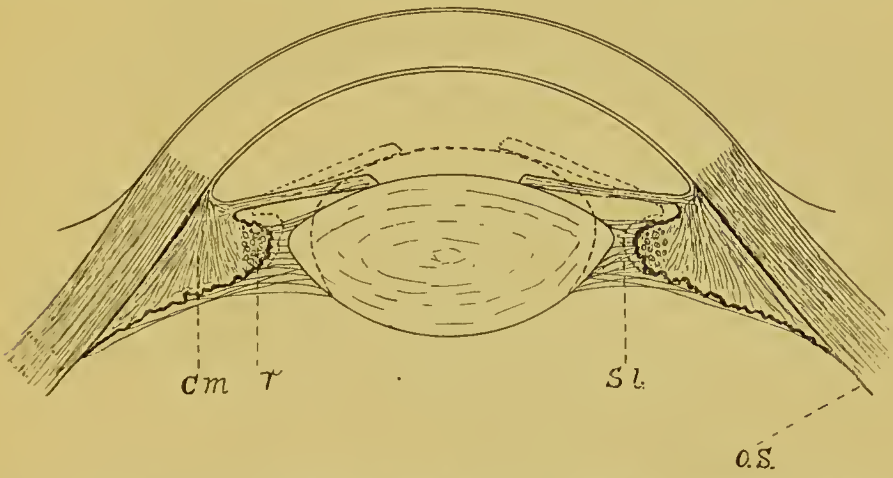


Fig. 13.—Diagrammatic Horizontal Section, showing Parts of the Eye connected with Accommodation.

The dotted line shows the form of the crystalline according to Helmholtz, and the position of the iris during accommodation.

Cm, ciliary muscle ; *Sl*, suspensory ligament ; *r*, Müller's ring ; *Os*, ora serrata.

Fig. 14 represents diagrammatically the form of the lens according to Helmholtz. It should be compared with the corresponding sketch (Fig. 15) of the shape of the lens according to Tscherning.

Tscherning Theory.—Tscherning supposes that the increase in curvature is obtained, not by a relaxation, but by a direct *traction* of the ligament on the periphery of the lens. He supposes contraction of the ciliary muscle on itself so that the posterior extremity of the ciliary body is advanced and the anterior is receded. This contraction causes a sustaining pressure on the vitreous and on the posterior surface of the lens, simultaneously with tension exerted, through the medium of the ligament, on the front surface of the lens. The latter then becomes flattened at the periphery, while the central portion is increased in curvature owing to the resistance of the dense nucleus. Accommodation is, therefore, effected by a forcible distortion of the lens, giving to the anterior surface a curve approximating to a hyperboloid of revolution.

Fig. 14.

Lens Unaccommodated, Ligament Stretched.

Lens Accommodated, Ligament Relaxed.

Regarding the crystalline optical system as one consisting of a nuclear strong convex lens, whose power is reduced by the two cortical concave menisci, the action of accommodation, according to the Tscherning theory, is produced by an alteration in the form of the anterior meniscus, whereby it becomes less concave, afocal, or even convex in nature. Fig. 15 gives a diagrammatic view of the alteration in shape supposed to be undergone by the crystalline.

Fig. 15.

Lens Unaccommodated, Ligament Relaxed.

Lens Accommodated, Ligament Stretched.

The radii of curvature of the crystalline being 10 mm. and 6 mm. for the front and back surfaces respectively, and, assuming the posterior radius to be unchanged in Ac., the anterior radius would have to diminish from 10 to 6 mm. to give a near point of about 140 mm. calculated on the ordinary schematic eye.

Owing to sympathetic action between the sphincter ciliaris and sphincter iridis, the pupil markedly contracts during accommodation, the central portion of the iris apparently advancing, and the edges near the sclerocorneal margin somewhat receding. This contraction may be necessitated by the slightly increased intensity of illumination from near objects, but it is more probably necessitated by increased aberration.

The Catoptric Test.—This is sometimes referred to as Purkinje's or Sansom-Purkinje's test, and must not be confused with Purkinje's images described later on.

Viewed externally, both the cornea and anterior surface of the lens act as convex mirrors, and the posterior surface as a concave. Now, the size and distance of the image from the vertex of a mirror is directly proportional to its radius of curvature. If, therefore, the radius diminishes, the curvature and power increase, and the reflected image diminishes in size and approaches the vertex.

In Fig. 16 let M represent the front surface of the crystalline of given curvature and M' be the same during accommodation; let O be a luminous object situated on one side of the optic axis. Then the image formed by M is I_1, on the secondary axis OC_1. In the "accommodated" mirror M', the corresponding image is I_2, which is smaller and situated on the secondary axis OC_2, where C_2 is the new centre of curvature. I_1 and I_2 are situated practically at the principal focus of the mirrors M and M' respectively, or about half-way between the centre of curvature and the vertex. Therefore, to an eye E, placed on the opposite side of the axis to the object O, the reflected image during accommodation will be seen to move from I_1 to I_2, and the projections of these on the surface are represented by P_1 and P_2.

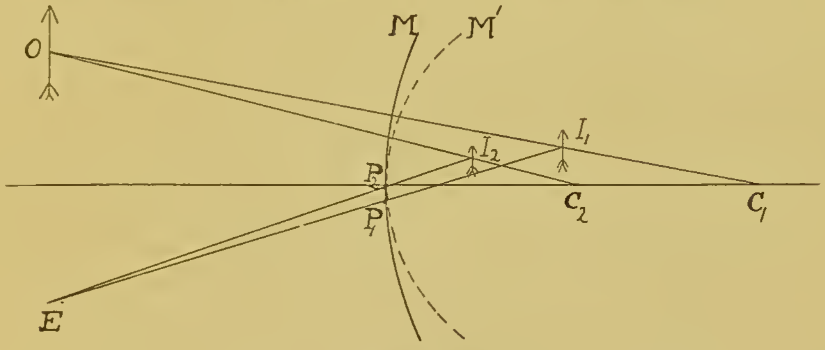


FIG. 16.

If a flame be held about 45° on the one side of the optic axis of a living eye, and the observer's eye be at an equal angle on the other side, there can be seen in the observed eye at rest—(1) a bright virtual image of the flame reflected from the cornea acting as a convex mirror; (2) behind the first a second virtual image reflected from the front surface of the crystalline, also acting as a convex mirror, this image being rather larger, more diffused than No. 1, and difficult to see; (3) a very small real image reflected from the back of the crystalline acting as a concave mirror.

When the observed eye accommodates, the second image becomes smaller, clearer, and advances sideways towards the centre of the pupil, thus showing that the front surface of the crystalline has become more convex. Images 1 and 3 do not change, indicating that the other surfaces are not affected by accommodation. As No. 2 is difficult to see, the candle should be moved about until the clearest image is obtained.

The Motor Muscles and their Actions.

The External Muscles of the eye, by means of which the globe is rotated, are six in number—the four recti and the two obliques—as described in Chapter I. By their aid the eye can, within certain limits, rotate or make excursions in every direction.

Rotation of the Eye.—The six motor muscles constitute three pairs, in each of which the one muscle acts antagonistically to the other; the first pair is completely and the second and third pairs partially antagonistic.

The *first* pair consists of the external rectus, which turns the front of the eye *out*, and the internal rectus, which turns it *in*. Thus, for example, if the eye is directed outwards, the external rectus contracts, and at the same time the internal rectus relaxes.

The *second* pair consists of the superior rectus, which turns the front of the eye *up* and *slightly in*, and the inferior rectus, which turns it *down* and *slightly in*.

The *third* pair consists of the superior oblique, which turns the front of the eye *down* and *out*, and the inferior oblique, which turns it *up* and *out*.

Rotation of the eyes is effected in a series of short jerks, and not by a continuous movement, unless the gaze be fixed on a moving object.

Pair.	Muscle.	Action on the Eye.
First	Internal rectus	Directly inwards
	External rectus	Directly outwards.
Second	Superior rectus	Upwards and slightly inwards
	Inferior rectus	Downwards and slightly inwards
Third	Superior oblique	Downwards and outwards
	Inferior oblique	Upwards and outwards

These directions refer to the front of the eye; the macula in each case turns in the opposite direction.

When a rectus contracts, the front of the globe turns towards the contraction, and the name of the rectus muscle which acts indicates the direction towards which, externally, the visual axis is turned. When an oblique contracts, it is the back of the eye which is primarily acted on, so that the front of the globe rotates in a direction contrary to the name of the muscle.

Axes of Rotation.—There are three principal axes of rotation—

The vertical axis, around which the eye is rotated by the internal and external recti, is perpendicular to the horizontal plane of the eye (Fig. 17) and passes through the centre of rotation.

The transverse axis, *GH*, around which the eye is rotated by the vertical recti, lies in the horizontal plane, and forms, with the optic axis, an angle of about 70°, being inclined forward on the nasal, and backwards on the temporal, side from the true horizontal axis, being about 20° therefrom.

The oblique, or fore and aft axis, *EF*, around which the eye is rotated by the two obliques, lies also in the horizontal plane, and forms, with the optic axis, an angle of about 35°, being inclined forwards on the temporal, and backwards on the nasal, side. It lies, therefore, some 55° from the plane of the equator. The axes, *GH* and *EF*, are nearly at right angles to each other, and are inclined to the axis of symmetry *AB* and *QQ*, because the vertical recti and the obliques pass obliquely to their attachments from their origin at the nasal side of the globe.

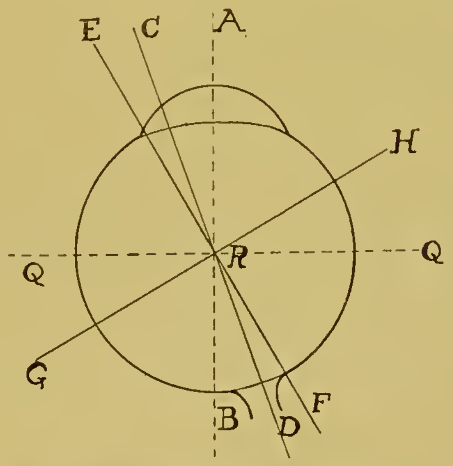


FIG. 17.—DIAGRAM SHOWING THE AXES OF ROTATION, AND, *CD*, THE AXIS OF THE ORBIT OF A LEFT EYE.

Centre of Rotation.—The three axes cross each other at *R*, the *centre of rotation* (or centre of motion), this point being situated on the optic axis about 13 mm. behind the cornea, or 9 mm. in front of the retina, 6 mm. behind the nodal point, and therefore about 2 mm. behind the geometrical centre of the globe. Around *R* all the excursions of the eye take place, it being the one stationary point of the globe. The centre of rotation is presumed to be situated on the optic axis, but that it lies considerably behind the iris can be demonstrated by the experiment of Professor Barratt of Dublin.

Place on the wall a vertical strip of white paper, *S* (Fig. 18), occlude one eye, and hold a card, *D*, close to the other, between it and the strip, so that *D* just hides the latter. Then, without shifting the head, move the eye to fix a spot about 2 yards to the left, when the paper will come into view. No light from S can enter the eye when the visual axis is directed to V, but when it is rotated around C to V', light from S can enter the pupil and form an image on the retina.

A Cardinal Motion results when the eye is rotated directly upwards, downwards, or laterally from the primary position. *Duction* is rotation; whence *abduction* (abversion) is rotation outwards; *adduction* (adversion) inwards; *dextroduction* to the right; *lævoduction* to the left; *superduction* (elevation) upwards; *subduction* (depression) downwards.

Translation, or displacement of the eye, occurs whenever it is rotated, owing to the centre of motion being behind the centre of the globe; it is, however, very small and therefore unnoticeable.

Primary and Secondary Position.—The *primary* position is that of an eye when all the muscles are at rest, and normally this would be when the eye is looking straight forward at a distant object. Any deviation from the primary is a *secondary* position, and results when the motor muscles are put into action. The direct secondary positions are indicated by the direct actions of the individual muscles on the globe; intermediate secondary positions result from combined action of two or more muscles.

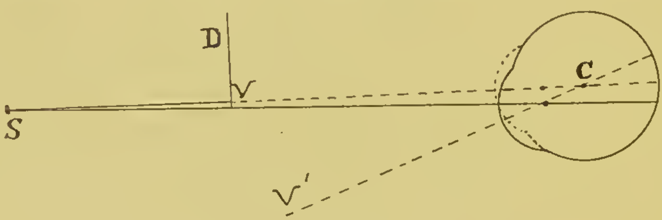


FIG. 18.

When the eye is rotated obliquely in any direction, the motion may be regarded as the resultant of two cardinal motions and the resultant action of two or more muscles. Generally two recti and one oblique are united in oblique rotations. There is no single muscle which can cause a direct vertical motion, or rotation around the optic or visual axis.

Listing's Law.—"*When the line of fixation passes from its primary to any other position, it is as if the eye had arrived at this position by turning around an axis perpendicular to a plane containing the first and second positions of the line of fixation.*"

To look, say obliquely, upwards and outwards at a certain point, the eye could be turned up nearly level with the point and then rotated outwards until the visual line reached it. The result is the same if the line of fixation be directed by the shortest route from the first to the second point—that is, rotated in a plane containing those two points, round an axis which is at right angles to that plane. Motion around what may be termed a Listing axis is achieved by the combined action of three muscles. The time occupied, the actual angular movement, for elevation or depression, are less when the eye is turned directly in an oblique direction than if it were turned first vertically and then horizontally.

Listing's plane is a vertical transverse plane which contains vertical and horizontal axes of rotation, and therefore also a centre of motion. In the primary position it may be considered coincident with the plane of the equator. Listing's axes are meridians of this plane.

Torsion.—True voluntary torsion, or rotation around the optic or visual axis, cannot occur for the reason that the action of any muscle causes the macula to move contrary to the corneal vertex. If, however, the eye be rotated on an oblique axis, a *false* involuntary torsion occurs. The vertical meridian of the eye is then no longer perpendicular to the plane of the horizon; the upper and lower parts of the cornea turn, the one towards, and the other away from, the nose. It is usual to refer such torsion to the inclination of the *upper part* of the cornea; thus:

Intorsion occurs when it is towards the nose; *extorsion*, towards the temple; *dextrotorsion*, towards the right, as when looking upwards to the right or downwards to the left; *lævotorsion*, towards the left, as when looking upwards to the left or downwards to the right. False torsion ensues on rotation of the eye around an imaginary oblique axis, as well as on rotation around the axes of the obliques and the vertical recti. The torsion produced is proportional to the angle through which the eye is rotated.

Thus the muscles can cause rotation of the eye around a vertical or horizontal axis, or around one *intermediate* to the two, but not around an antero-posterior axis; normally, no wheel-motion of the meridians of the eye is possible. Real torsion, or rotation around the optic or visual axis, could be effected by the united action of the superior rectus and superior oblique. The first causes superduction, adduction, and intorsion; the latter causes subduction, abduction, and intorsion; the vertical and horizontal movements are neutralized, and intorsion alone remains. Similarly, the inferior rectus and oblique can unitedly cause extorsion. In these cases the *intermediate* axis before referred to would correspond to the antero-posterior axis of the globe, or, rather, to the visual axis; these pairs of muscles are, however, not normally associated.

Demonstration of Rotation can be made by the following experiment: Let an orange (Fig. 19) represent the eye, mark a point for the pupil, and draw two lines AB and DE to represent respectively the vertical and horizontal planes of the eye. Pass a hatpin or knitting-needle, P_1P_2, through the centre C horizontally, and parallel to AB, and another P_3P_4 vertically and parallel to DE. If, to represent the eye looking directly upwards or downwards, or to the right or left, the orange be rotated around either of these pins, there is no torsion. If another pin, not shown in the diagram, be passed obliquely through *C* in the horizontal plane, and the orange rotated around it, the horizontal and vertical planes *AB* and *DE* become oblique. The same occurs if, in order to arrive at the same direction, it be rotated first around the horizontal and then around the vertical pin.

Antagonistic and Associated Muscles.—All the muscles have their origins more to the nasal side of the eye than their insertions. The vertical recti, being inserted into the sclerotic *in front of the equator*, therefore cause adduction of the cornea, and the two obliques, being inserted *behind the equator*, cause abduction. If the line of vision is to be raised vertically, the superior rectus alone will not effect it, since its action turns the eye not only upwards, but also inwards, and intorts it as well. To produce direct elevation of the eye there is needed also the inferior oblique which has, in addition to that of elevation, abductive and extorsive actions. The action of the inferior oblique neutralizes the adduction and intorsion of the superior rectus, while it assists the elevation, so that the two combined turn the eye directly upwards. In the same way the inferior rectus, in addition to depressing the eye, causes adduction and extorsion, which is corrected by the superior oblique which depresses, abducts, and intorts; the two combined cause the eye to be rotated vertically downwards. Hence we find that the superior rectus and inferior oblique are associated muscles in elevation, but otherwise antagonistic. Similarly, the inferior rectus and superior oblique are associated in depressing the eye, but are otherwise antagonistic. Every muscle must have an opponent to allow of its steady and direct motion:

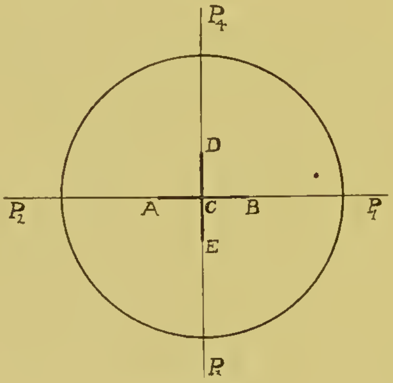


Fig. 19.

The horizontal recti are direct opponents to each other horizontally.
The vertical recti are opponents vertically.
The obliques are opponents vertically.

The superior rectus and inferior oblique are opponents laterally and torsionally.
The inferior rectus and superior oblique are the same.
The superior rectus and superior oblique are opponents vertically and laterally.
The inferior rectus and inferior oblique are the same.
The internal rectus and the vertical recti are associated in adduction.
The external rectus and the obliques are associated in abduction.
The superior rectus and inferior oblique are associated in superduction.
The inferior rectus and superior oblique are associated in subduction.

ACTIONS OF THE MUSCLES.

Muscles.	Action.
Internal rectus Superior rectus Inferior rectus	.. .. .. Adduction
External rectus Superior oblique Inferior oblique	.. .. .. Abduction
Superior rectus Inferior oblique	.. .. .. Superduction
Inferior rectus Superior oblique	.. .. .. Subduction
Superior rectus Superior oblique	.. .. .. Intorsion
Inferior rectus Inferior oblique	.. .. .. Extorsion
Right external rectus Right superior oblique Right inferior oblique Left internal rectus Left superior rectus Left inferior rectus	.. .. .. Dextroduction
Left external rectus Left superior oblique Left inferior oblique Right internal rectus Right superior rectus Right inferior rectus	.. .. .. Lævoduction
Right inferior rectus Right inferior oblique Left superior rectus Left superior oblique	.. .. .. Dextrotorsion
Left inferior rectus Left inferior oblique Right superior rectus Right superior oblique	.. .. .. Lævotorsion

Associated action also takes place between the muscles of the lids and the vertical recti whereby the same portion of the globes is always covered by the upper lids as the eyes are raised or lowered. In addition there are further associated actions, as between the internal recti and the ciliary muscle in Ac. and Con., and between the ciliary and the sphincter of the iris.

Monocular and Binocular Vision.—Vision of each eye alone is *monocular*, that of both eyes is *binocular*. Binocular vision may be *single* and *simultaneous*, in which a single combined image results from the retinal impression of the two eyes; it may be *double*, in which two images result; or it may be *alternating*, in which there is single vision, because each eye alone alternately sees at a given moment. Unless otherwise indicated, *binocular vision* means single simultaneous vision; it is always better than monocular vision.

Fixation and Fusion.—The *point of fixation* is that to which the visual axis is directed, and on which the mind is fixed; its image is at the fovea, and, if binocular vision is single, it is at the fovea of each eye. The double stimulation is then united into a single mental impression, and the two ocular images are said to be *fused*. Fusion is the more perfect if the two eyes have equal vision, and may become difficult, or even impossible, if they have not.

The Visual Axes.—When the muscles are at rest, the visual axes are normally directed to the same point at infinity. They are then presumed to be parallel, although actually they are very slightly convergent, for if they were not, a small distant object would not be seen singly.

Yoked Muscular Actions.—Combined action of the muscles of the two eyes is termed *yoked* or *conjugate*. Thus, if the two eyes are turned to the right, the external rectus of the right eye is yoked with the internal rectus of the left. There is a yoked action of the two superior recti when looking upwards, of the two inferior recti when looking downwards, of the one internal and the other external rectus when looking sideways.

Convergence.—In order to see singly a near object, the two internal recti must contract, and the eyes turn inwards; then the visual axis of each eye is directed towards the object, and its image is formed on both maculæ; if convergence does not occur, either one eye only sees the object, or the latter is seen double. Convergence is the most important of the yoked actions, and is independent of, and can be exerted with, any of the others. The eyes cannot simultaneously be turned outwards by the external recti, so that voluntary divergence beyond parallelism of the visual axes is impossible, although divergence may result as an abnormality. It can, however, be effected to a limited extent, say 2° each eye, by most people under the influence of a desire for fusion of the projected images; special stimulation is needed, as by presenting similar objects to the eyes or by prisms base in. Although the eyes cannot be diverged by a voluntary action of the external recti, yet when the six motor muscles of each are completely relaxed and at rest, as when the eyes are closed in sleep, the visual axes *do* usually diverge. This means that most people exert slight *convergence* in order to see singly a distant object, the primary position being one of divergence. Thus, when the eyes are open, and when they are closed, the term "at rest" has a slightly different significance.

Combined Muscular Actions.—As already stated, when the eyes turn in any direction, there is fairly complicated associated or yoked action of certain muscles. For instance, the two superior recti are yoked when the eyes look upwards, but, at the same time, other muscles acting in conjugation are stimulated; thus the two inferior obliques must act to prevent the eyes from turning in. If the eyes are turned to the left as well as upwards, the external of the left and internal rectus of the right are also yoked and besides these, other muscles would be partially associated in elevation, lævoduction, and lævotorsion, so that fusion of the images may occur as perfectly as possible.

Relationship between Accommodation and Convergence.—There is an inherent connection between these two functions. Normal eyes exert neither for vision at ∞, and exert equal quantities of each for any near distance. There is so intimate a connection between the two that it is difficult for the one to be brought into action without the other, and, conversely, it is easier for either when the other is also stimulated. Nevertheless, this connection between the two functions can be severed voluntarily or mechanically. Thus Cc. lenses, which cause increased Ac., or Cx. lenses, which lower Ac., may be seen through clearly without necessarily affecting Con. Prisms base in reduce Con.; prisms base out increase it; but these can be employed without Ac. of necessity being reduced or increased. One can learn to accommodate for a near object, and then relax Con. to parallelism, or even divergence, while still maintaining Ac. One can similarly learn to accommodate for a distant object and converge for a nearer one. Certain conditions of muscular imbalance and refractive conditions render these experiments either easier, or more difficult, or even impossible to achieve.

Con. is exerted when the eyes accommodate for a near object, but not usually to so great an extent if the one eye only fixes it. If a small object in the median plane be viewed at the reading distance, and the one eye be alternately and rapidly occluded and uncovered, binocular vision is not affected. If however, the one eye be occluded for several seconds and then uncovered, two images are seen, and these move quickly towards each other until fused; this occurs because full Con. is not exerted until the two eyes fix. Usually the images are crossed, as divergence of the eyes occurs when fusion by convergence is not in force.

The Law of the Macula.—Lindsay Johnson found that among the Simiæ (*i.e.*, man and monkeys), without exception, the optic axes are practically parallel—*i.e.*, the two eyes are directed straight forwards when regarding a distant object. Furthermore, they alone among the mammals possess a small central area of highly acute vision, together with the power of convergence. Hence parallel vision, the power of convergence, and the possession of a macula are always found together. A law may, therefore, be formulated that all mammals which have parallel vision and the power of convergence possess a macula, and all animals which possess a macula have parallel vision and the power of convergence. All other mammals possess a marked divergence of the optic axes, which increases as the natural orders descend until, in the rodents (hares, etc.), the optic axes are at right angles to the median line of the body. This is also the case in many of the birds, nearly all reptiles, amphibiæ, and fishes. In animals below the monkeys, in place of the macula a specially sensitive visual area exists which, as a rule, forms a long narrow strip spreading horizontally across a variable length of the fundus, and may be situated either close above or close below the optic disc. Hence we may assume that acute vision in such animals is inferior to that of man and monkeys, but is superior as regards a large area of equally good vision. The optic axes are never really parallel in any animal, for, even in man, they each diverge slightly from the median line, although, as an abnormal condition, they may be parallel, or even convergent.

With the exception of the Simiæ, mammals do not habitually move their eyes to any marked degree from the primary position; they turn the head instead. An exception occurs among domestic cats and dogs, which occasionally converge slightly when food is held in front of the nose. Reptiles and fishes, however, move their eyes, as do many birds.

Stereoscopic
field of vision

CHAPTER III

VISION

The Sense of Sight.—The eye is said to be the first sense organ developed in the embryo. After touch it is also the most universally distributed sense, existing, except in the very lowest forms of life, throughout the animal kingdom. Sight is the chief factor in the education and intellectual development of man; by its aid the form, colour, size, distance, position, and characteristic details of objects become known. The mental process of projecting upright images from inverted retinal images is natural, it being apparently present in earliest infancy, and the faculty is never lost.

The sense of sight lies, not in the eye, but in the brain. The retinal stimulus is interpreted in the form of a projected virtual mental image of the object, the sensation, excited by the impingement of the light rays on the retina, having been communicated to the brain by means of the fibres of the optic nerve. From experience and education the rays are referred back to a distance closely coinciding with that which they travelled before entering the eye. Thus the projected mental image usually corresponds in every respect—in position, distance, size, etc.—with the object viewed. It is not the object, but the mental picture that is seen, although it is commonly said that one sees the object itself, and this is certainly the most convenient way of expressing the phenomenon of vision.

Faculty of the Retina.—The retina has a *receptive* faculty; it does not see, but merely receives the impression from which the mental appreciation of an external object results. Sight is a faculty of the brain, but, since clearness of vision is directly proportional to the number of cones existent in that part of the retina on which the image is formed, it is customary to refer to the *perceptive* faculty of the retina.

The Optic Nerve.—The optic nerve is incapable of conveying any sensation other than that of light. If it be touched or injured, nothing but the sensation of a flash of light results.

The optic nerves, after passing through apertures at the back of their corresponding orbits, meet each other at the *chiasma* in the median plane immediately beneath the brain, and many of the fibres cross (decussate) over to the opposite nerve, so that after meeting, each is composed partly of its own fibres and partly of the fibres of the opposite nerve. The bundles of fibres, now termed *optic tracts*, proceed thence to the brain (Fig. 20).

The cerebral ends of the nerve fibres do not seem to be arranged in regular order, as are their other ends at the retina, but apparently this does not interfere with the formation of a correct mental picture of an external object. Each retinal terminal receives a stimulus from its corresponding point on the object, such stimulus being then transmitted to the brain cell at the other end of the fibre; this being done, the individual sensations are assigned their correct position in the mental picture. The exact process of mental interpretation is, however, unknown, and when the light wave reaches the retina our knowledge with regard to vision ceases. We do not know the nature of the force which conveys the sensation, nor can we assign their respective functions to the known centres of vision.

Divisions of Visual Perception.—The sense of sight may be divided into three classes of perception, viz., light, form, and colour.

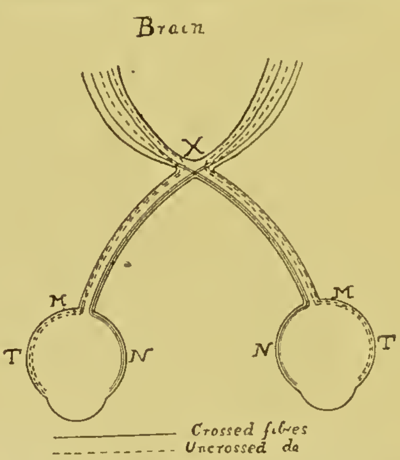


FIG. 20.—DIAGRAM ILLUSTRATING THE COURSE OF THE FIBRES OF THE OPTIC NERVES FROM THE EYES TO THE BRAIN.

The fibres belonging to the nasal half of the fundus cross over, at the chiasma, to the opposite hemisphere of the brain. The fibres which are distributed over the temporal half of each eye are confined to its corresponding side of the brain. Thus the right halves of the two visual fields go to the right hemisphere, while the two left halves pass to the left.

N, Nasal; *T*, temporal; *X*, chiasma; *MM*, maculæ.

The *light sense* is the faculty of distinguishing illumination and its graduations of intensity. The distinction between light and darkness is the lowest degree of this faculty, and if it be absent there is complete blindness (vide *Visual Threshold*); on the light sense depends the power of the retina to adapt itself to various degrees of illumination. It forms the only visual sense in many of the lower forms of animal life.

The *form sense* is the faculty of recognizing outline or shape; it requires a transparent refracting body to collect the light and form a real image, a conducting apparatus and a sensory organ.

The *colour sense* is the highest development of vision, and enables the eye to appreciate light waves of different frequencies.

In general, of course, all three divisions of visual perception are present; but any one, two, or all three may be lacking in a particular case.

Visual Projection.—The mental projection of each point of the image is outwards through the nodal point, in the direction of the axial ray of the incident beam of light producing that point in the retinal image.

For example, in Fig. 21, let N be the nodal point of an eye, and suppose some point A on the retina be stimulated by pressure through the sclerotic; a manifestation, called a *phosphene*, is immediately projected into space through N in the direction A'. Or suppose B to be an opacity in the vitreous casting a shadow b on the retina; the mental image of the shadow is projected toward B'. Lastly, suppose a very oblique pencil of light, R, be incident such that no entering ray at all can pass through N. Notwithstanding, the retinal image r is projected through N towards R', which, owing to the aberration caused by extreme obliquity of the incident light, may not be in the true direction of the object at all.

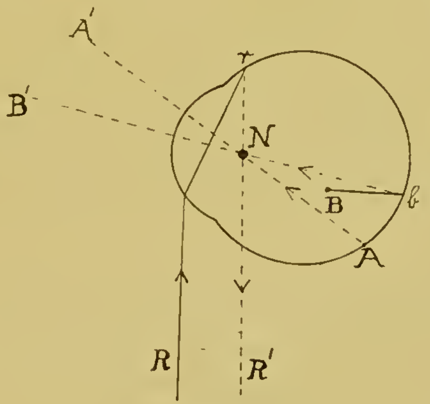


Fig. 21.

The position of the brain image, in space, is formed according to the particular part of the retina on which light falls, and not according to the original direction of the light. Thus, if the retinal image be formed by rays reflected from a plane mirror, the brain picture is conceived behind the mirror, at the same distance from its surface as the object itself is in front of it. One can see in a mirror (and therefore in front of him) the images of objects actually situated behind his back, for the rays, having entered the eye from the face of the mirror, are mentally projected in that direction.

If the retinal image be formed by rays refracted by a prism, the object appears shifted towards the edge, because the rays, after refraction, being turned towards the base, enter the eye as if they came from an object situated in a position nearer the edge, and are mentally referred back accordingly. Again, an object viewed through a convex or concave lens is seen respectively larger or smaller, the light diverging from each object point being, in the first case, less divergent after refraction and therefore projected to a greater distance; and, in the second case, more divergent and therefore projected to a shorter distance. Thus the image of an object seen through a prism or lens is as distinct as if nothing were placed between the eye and the object, but as it does not correspond with the latter, we commonly say that we see its image.

The faculty of visual projection is inherent, although, with respect to distance, it appears to be acquired. A baby obviously makes mistakes in the distance of an object he wishes to grasp and a person who sees things under new conditions, as through lenses for the first time, may misjudge the distance of an object, but he will never conceive it as upside down or displaced laterally. One who is in the habit of seeing things under certain conditions judges much better their distance than one to whom such conditions are new. We can obtain inversion by viewing an object through a strong convex lens held some distance in front of the eye; we then see in the air a real inverted image of the original object. From this real image the light diverges and produces on the retina an upright image, so that the mental interpretation is that of an inverted impression of the original object. The same occurs if a landscape be observed through an astronomical telescope, or in a concave mirror held sufficiently far away from the observer's eye

Direct and Indirect Vision.—For an object to be seen clearly, vision must be *direct*—that is, its image must be formed on the macula. In direct vision the visual axis connects the fovea, or centre of the macula, with the point of fixation, so that direct vision occurs obliquely to the optic axis in the direction of the visual axis. When an image is formed on any part of the retina other than the macula, vision is *indirect*, and the force of the impression conveyed to the brain decreases as the distance from the macula increases. Were the receptive faculty of the whole retina equally acute, vision would be extremely confused, since it would be impossible for the brain to appreciate at the same moment so many details.

Direct Vision.—Only a moderately sized image—*i.e.*, one which subtends an angle not exceeding, say, 4°—can occupy the macula at a given time. The object, of which this is the image, is appreciated distinctly, while everything else within the angle of view is seen with a varying degree of indistinctness. The more distant the object, the greater is that part of it which can have its image on the macula, and can therefore be included in *direct vision*. The nearer the object, the smaller is that portion which can be seen clearly at a given moment. Thus, in reading, a couple of short words comprises all that can be distinctly seen without moving the eyes or the book; or to use a familiar example, the image of a shilling at 10″ will cover the area of distinct vision. The area of really critical vision is, however, confined to the fovea. Other parts of the image, falling on less sensitive portions of the retina, are seen with a degree of distinctness only sufficient to assist in the recognition of general outlines.

Indirect Vision.—Although peripheral sight is so imperfect that one can only perceive vague outlines, indirect vision is of extreme value. It enables the direction, position, and movement of objects outside the area of critical vision to be noted, and, indeed, estimation of movement seems to be a faculty possessed by the peripheral portion of the retina to as great an extent as, if not greater than, that of the more central regions. A person with a contracted field is unable to cross safely a street, although he may have practically normal central vision, whereas another, who has worse central vision but a normal field, can safely do so. One has only to see and move about with a tube before one's eye to realize the importance of peripheral vision.

Visual Separation of Adjacent Points.—Other things being equal, the clearness and minuteness of detail of the object seen is in direct proportion to the number of retinal cones stimulated. When it is necessary to view an object with precision, the light from it must fall on the macula, where the retinal elements are most closely packed. Any two points on the object can then be distinguished as two provided that each point image occupies a cone, and is separated from the adjacent point by a distance also equal to the diameter of a macular cone, namely, 0·002 mm. Outside the macular area the cones are larger.

Estimation of Direction depends on indirect vision. The direction of an object is estimated from the part of the retina which receives the impression, and on the position, relative to the macula, of the part of the retina so impressed. If the image is to the right of the macula, the object is conceived to be to the left of the observer; if to the left of the macula, it is taken to be on the right. If the rays impinge on the retina above the macula, the object is mentally projected towards the ground; if they fall below, it is conceived upwards.

Estimation of Position of an object as so much to the right or left, above or below, depends also on indirect vision or on the motion of the eye or head made to fix it.

Estimation of Motion depends on the fact that the image of the object passes over the retina, and so successively occupies gradually varying distances from the macula; or alternatively, it depends on the amount of rotation of the eye necessary to keep the image of the moving object on the macula. The motion thus conceived represents, however, only a change in the relative positions of the object seen and of the observer, and since the object, or observer, or both, may have altered their position, the estimation of motion is sometimes deceptive. Thus, when viewing a landscape from a moving train, the telegraph poles, fields, and houses seem to pass the train rather than the reverse. If one be seated in a stationary train, and another alongside starts moving, the observer may imagine that it is his train which has started. He can only be certain whether he or the object viewed is moving when something helps to confirm the one or the other fact. The muscular action exercised when walking or the jolting experienced when driving usually serves to prevent an error of judgment in this connection. The optical illusion of telegraph poles passing a moving train does not occur if the observer views the more distant as well as the near landscape, for then the former appears, by parallax, to move with the observer, while the latter appears stationary.

Conception of the amount or celerity of movement depends on the extent or rapidity of the change of position of the image or on the action of the motor muscles necessary to keep the object in view. The more distant the object in motion, the smaller is the apparent movement, because the object in a given time moves through a smaller angle. When the object is near, it moves through a greater angle in a given time, and therefore its image traverses a larger retinal area, or a greater muscular action is needed to keep it in view, so that the rate of progression seems more rapid.

When a very distant object is seen it is difficult to judge whether it is stationary, moving away from, or coming towards the observer. The image occupies the same position on the retina; no muscular action is needed to keep it in view, and for a certain length of time there is no appreciable change in the size of the retinal image. Only when the retinal image becomes appreciably smaller does the mind conceive that the body is moving away, or when the diminished distance causes an increase in the size of the retinal image can the observer be sure that the object is approaching.

Appreciation of motion being the conception of successive changes of direction, the peripheral portions of the retina are very sensitive to it, and the motion of an object seen by indirect vision can be justly estimated. If the movement of a body is exceedingly rapid, it may fail to excite the retina at all. One cannot see the passage of a bullet, and lightning, owing to the rapidity of the change of direction, simply causes the mental sensation of a continuous streak of light.

Estimation of Form is dependent on the mental recognition of the outline of the retinal image, and for flat surfaces this suffices. It almost entirely depends on central vision, since the peripheral portion of the retina is comparatively insensitive to form.

Estimation of Solidity.—The form of a solid body is similarly conceived, but there is, in addition, the mental appreciation of the shadows caused by it, and of the position of other bodies in relation to it, which aid considerably in the recognition; but the principal assistance is derived from the slightly different view of a solid body presented to the two eyes—in other words, the *stereoscopic* effect.

Estimation of Size of an object depends chiefly on the extent of the retinal area occupied by its image, and therefore on the number of rods and cones stimulated. As previously mentioned, the size of the retinal image is governed by the visual angle, so that the apparent size of an object decreases directly as its distance from the eye. An object distant 1 yard subtends a certain sized visual angle, which becomes practically half that size if the distance between the object and the eye be increased to 2 yards, and one-fourth the size if the distance becomes 4 yards. But habit and the unconscious comparison with .surrounding objects of known size enables the observer to estimate, independently of the visual angle, the true dimensions of an object, so that one does not imagine a thing to be half the size of another similar object merely because the one is at double the distance of the other.

A white object against a black background appears larger, and a black object against a white background smaller, than it really is. This is due to *irradiation* or *halation*, which is the encroachment of the white image on the neighbouring black space, with the result that the black appears diminished and the white increased in size.

Estimation of Distance results from habit and education. If the object be very distant, but yet recognizable, as, say, a cart or man, its distance is estimated from the extent of the retinal image—*i.e.*, its distance is estimated from its apparent size. Soldiers unconsciously judge the distance at which certain details—for instance, the arms, eyes, or buttons—of an enemy can be seen. When the conditions under which the object is viewed are unusual, estimation of distance is more difficult, which proves that something beyond comparison of the size of the present retinal image with the remembered size of a similar object placed at a known distance is needed. In Africa and other parts, owing to the dryness and purity of the atmosphere, distant objects are seen very distinctly, and to those unaccustomed to the climate seem to be nearer than they really are. Distances are deceptive to most people in foggy weather, and they cannot be accurately judged by the landsman at sea nor by the townsman in the country.

Aids to Estimation of Distance and Size.—From what has been said it will be seen that conception of size and distance are closely connected, and, indeed, can hardly be separated. It is comparatively easy to estimate the distance of objects within about 20 feet, because we are more accustomed to seeing close objects, and, in addition, we are aided by the muscular action involved in convergence and accommodation, and by the stereoscopy of binocular vision. The nearer the object is situated, the more convergence and accommodation are exerted; consequently, the greater the exertion the shorter is the distance of the object conceived to be. Anything which induces these functions without altering the apparent size of the object also causes the latter to seem nearer—*e.g.*, prisms, base out, make an object viewed through them seem nearer, while prisms, base in, have the contrary effect.

As red light, to be focussed at the retina, needs more accommodation, a red object seems nearer than any others at the same short distance, at least, this is so in emmetropia and hypermetropia, but myopes often state the reverse. If there be diplopia, and a red glass be placed in front of the one eye, a candle flame seen by it usually appears nearer than the other. Nevertheless, when the distances of differently coloured bodies are compared, what appears nearest to one person may not seem so to another.

Convergence and accommodation also unconsciously help in judgment of size. If an unknown object causes a certain-sized retinal image, and requires a certain effort of convergence and accommodation in order to be clearly seen, it is conceived to be of certain dimensions. The same retinal image, combined with smaller muscular efforts, would give the appearance of greater size, while greater efforts would cause it to be thought smaller. If, however, in order to cause accommodative effort a concave lens be placed before a normal eye, the object generally appears more distant, notwithstanding the extra muscular effort. In this case the diminution in the size of the retinal image more than counteracts the sense of nearness produced by the accommodation. For a similar reason a convex lens may cause the sensation of nearness, since the size of the retinal image predominates and the effect of increased distance, due to the suppression of accommodation, is lost.

The effect of a telescope or opera glass is to increase the size of the visual angle without calling into play any muscular effort. An actor on the stage seen through an opera glass simply appears to be nearer by an amount equal to the magnification of the glass. If the latter enlarges three diameters, it apparently brings objects up to a third their actual distance, and so on. Looking at an object through an opera glass the reverse way causes the impression of increase of distance equal to the magnifying power.

The conceived or apparent size of an object depends also on the distance to which its image is mentally projected, and generally the plane of the image is the same as that of the object. If, however, the plane of the object be unknown, this may, or may not, result. If possible, the mind always unconsciously seeks a plane on which to project the image. Thus the figures in a picture are projected on to the picture, the image of the whole picture itself is projected on to the wall on which it hangs. The mental image of a real aerial image, formed by a lens or mirror, is projected on to the plane of the lens or mirror, as being the nearest tangible body. The distance and, therefore, the size of a distant small body lying in front of a large one is difficult to estimate, as the image of the small body is projected on to the larger one. In other words, we cannot appreciate the gap between two distant bodies situated in the line of sight.

Comparative Size.—The estimation of the comparative sizes of various objects depends on their images being formed successively on the macula by means of rapidly achieved movements of the eyeball, so that the different retinal areas stimulated by the images are mentally compared. If objects are close together and in the same plane, comparison of their sizes is easy, but not so if they are widely separated or in different planes. Although the myope has a large retinal image and the hypermetrope a small one, the comparative sizes of different objects—and it is by comparison one judges—is the same for all eyes. Everyone must judge an object that is 1 foot long to be one-third the length of another 1 yard long.

Stereoscopic Fusion and the Sense of the Three Dimensions.—For persons accustomed to binocular vision, it is difficult to accurately estimate depth when one eye is closed. Unknown objects seem more or less without depth, and it is only the knowledge of the real form of objects, aided, as mentioned, by shadows and neighbouring objects, that prevents the idea of flatness. Even with binocular vision small objects situated beyond, say, 50 feet appear more or less flat, as then oblique binocular view is absent.

Height and width can be estimated almost as well by a single eye as by two, but both are required for the estimation of depth. How binocular vision helps in the estimation of dimensions may be noted by viewing a near object first with one eye alone and then with both. Thus, if a cubical box be viewed simultaneously by both eyes, the image of the outline of the front surface is received by each; since the images occupy corresponding positions on the retinæ, the projected mental images are fused. If the box be not too large the right eye also receives an image of the right side, while the left has an image of the left side. Each eye sees its corresponding side of the solid body, which may be invisible, or, at any rate, less visible, to the other eye.

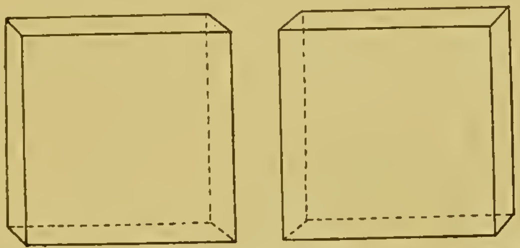


Fig. 22.—The Sketches illustrate the Views obtained by the Left and Right Eyes respectively of a small Cubical Body slightly below them.

The sense of three dimensions can, however, be present when binocular vision is absent. This is instanced in persons who, having lost an eye, by habit and experience have quickly acquired the sense.

Therefore solidity and the mental estimation of the comparative distances of objects, or parts of the same object, depends largely on binocular vision and the exertion of convergence. The latter sense is extremely delicate, a minute change in the angular relation of the visual axes being interpreted by the brain as a change in the distance of the fixation point. Accommodation, when the object is fairly close, also plays a part in the production of the stereoscopic sense. The sense of solidity due to the slightly different views obtained by the eyes of any object within reasonable distance, because, as before stated, the right eye sees more of the right side of an object, and the left eye correspondingly more of the left side, necessitates fusion of slightly dissimilar images on the retinæ and so gives rise to the sensation of stereoscopic or plastic relief. The interocular distance, however, is small, and therefore the judgment of distance and relief is feeble at any considerable distance, and ultimately ceases altogether. It follows that any device artificially increasing the interocular width will result in a corresponding increase in plasticity of an object, and stereoscopic relief will be obtained at greater distances than is normally possible. Prismatic binoculars are therefore made with their objectives wider apart than the eye-pieces, so that the difference in view, as seen by each eye, may be as great as possible. In all forms of range-finders the base line, or distance between the two points of view, is made as wide as possible in order to produce a parallactic effect at great distances.

The plasticity resulting from binocular vision and the power of convergence can be imitated by means of the stereoscopic camera and stereoscope. The camera is of the usual type, but fitted with two equal lenses, the width between which may be about 2½ inches—that of the interpupillary distance—but generally their separation is rather more to enhance the resulting sense of depth and solidity. Two photographs simultaneously taken of the same object then differ slightly from each other, just as the retinal images are slightly dissimilar. Prints of the two negatives are taken and transposed, so that, when viewed side by side, the right-hand print is that taken through the right lens, and the left-hand print that taken through the left. When these are placed in a stereoscope and fused, by means of sphero-prisms, the images fall on identical portions of the retinæ, and the prints will be seen as a single picture standing out in bold relief. The plasticity of the image is purely artificial, and is caused by the slight change in convergence that must be constantly exerted for the varying distances between the various corresponding points in the two pictures. The wider apart any two corresponding points, the less convergence is required to fuse them, and therefore the greater is their distance mentally conceived to be. Similarly, another pair of points, with less separation, will require more convergence for their fusion, so that the single image formed by those points is conceived to be nearer. Slight but unconscious changes in convergence are, therefore, rapidly made as different parts of the picture are viewed, and it is this constant variation in convergence that gives rise to the stereoscopic effect. Two pictures taken from the same standpoint will not, of course, give any sense of plasticity, since the degree of convergence is the same for all points of the combined image, which, therefore, appears quite flat.

Plastic effect increases with the distance apart at which photographs of an object are taken, and also with their magnification. Photographs of a constellation taken at six months' interval give a base line of 186,000,000 miles, which is sufficient to obtain a stereoscopic effect between some of the nearer stars. Photographs of a planet taken at an interval will, owing to the movement of the earth during that time, give a pronounced sense of depth between the planet and the fixed stars behind it.

Pseudoscopy.—If the prints are not reversed when placed in the stereoscope—*i.e.*, if the picture taken through the right lens be placed in front of the left eye, and *vice versa*, a *pseudoscopic* effect the reverse of stereoscopic relief is seen. In other words, those parts of the picture that should occupy the foreground are apparently behind those that should occupy the background, and so on. Thus a spherical body is seen hollow, and the images of actually nearer objects appear at a greater distance than those of more remote ones.

Stereoscopes.—Brewster's stereoscope, the one generally used, consists of a box fitted at one end with a pair of sphero-prisms, having the bases out to assist in the fusion of the images on the retina, and the right and left pictures are seen only by the corresponding eyes. Accommodation is not used because the stereograms are at the focal distance of the Cx. lenses. Brewster's stereoscope is limited to pictures about 3 inches square, but others take much larger prints and give better results.

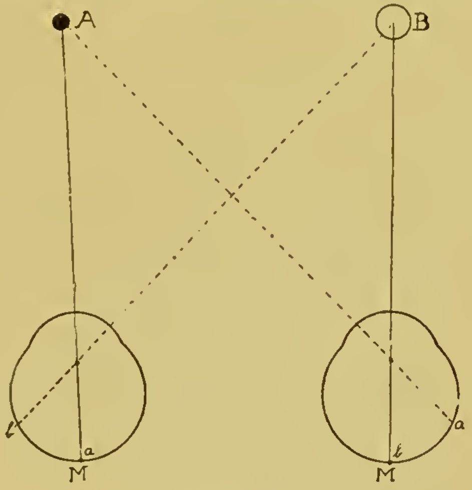


FIG. 23.

A and *B* represent the stereograms separated by a distance equal to that between the eyes, so that the latter are diverged to parallelism in order that an image of each may be formed on the corresponding macula *M*.

Stereoscopic Fusion without a Stereoscope.—The plastic effect of a stereogram can be obtained, without the aid of a stereoscope, in two ways.

In the abductive method (Fig. 23) two stereograms, not exceeding about 2 or 3 inches in size, reversed as for the stereoscope, are placed symmetrically in the median plane of the eyes. Convergence being relaxed, four images appear as the eyes move outwards towards parallelism, but the two inner ones approach each other, to overlap and become fused, when three pictures are seen. The centre one is now rendered clear by accommodation, care being taken that the convergence is not altered. There is a right and left uncombined non-plastic picture apparently separated by twice the distance they really are, and a combined plastic picture between the two.

In the right eye there is a macular image *b* of the picture *B*, and an image *a′* of the picture *A*, this being to the temporal side of the macula. In the left eye the image *b′* of the picture *B* is on the temporal side of the macula, while that of *a* of the picture *A* is at the macula. The uncombined images *a′* and *b′* belong each to the opposite eye, and are projected out as crossed according to the ordinary laws of projection.

FIG. 24.—SHOWING THE APPEARANCE OF THE COMBINED STEREOSCOPIC IMAGE *ab* BETWEEN THE UNCOMBINED CROSSED NON-PLASTIC PICTURES *a′* AND *b′* PROJECTED FROM THE RIGHT AND LEFT EYES RESPECTIVELY.

In the adductive method (Fig. 25) the stereograms are not reversed, but printed direct from the negatives. Convergence is first exerted for some point nearer than the stereograms, and, as in the abductive method, four images are seen, which become three on varying the convergence, so that the two middle ones fuse. The central image is now rendered sharp by relaxing the accommodation, the left uncombined picture belonging to the left eye, the right uncombined one to the right eye.

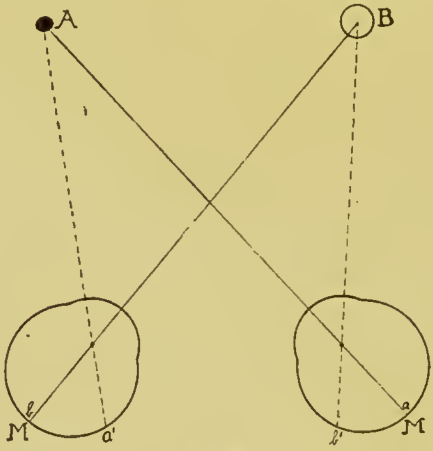


FIG. 25.

Here the right eye has a macular image *a* of the stereogram *A*, and to the nasal side an image *b′* of the picture *B*. The left eye has a macular image *b* of the stereogram *B*, and to the nasal side the image *a′* of the picture *A*. The appearance is the same as in Fig. 24, but now the uncombined images *a′* and *b′* are homonymous, and are projected from the left and right eyes respectively.

If reversed stereograms be used in the adductive method, the effect is not one of stereoscopy, but of pseudoscopy. Similarly, unreversed stereograms viewed by the abductive method give the effect of pseudoscopy. It is also worthy of note that in the abductive method the final image is apparently larger than either of the originals, and is due to the relaxation of convergence, whereby the object is mentally conceived to be at a greater distance, and therefore correspondingly larger. On the other hand, convergence in the adductive method gives rise to an impression of smallness, since the object is mentally interpreted as a nearer one.

The Field of Vision is the area over which an eye can see indirectly, the visual axis being directed straight forward. It is usually measured by the perimeter, as described later.

The normal field extends *approximately :* Upwards 50 degrees, downwards 70 degrees, or altogether 120 degrees in the vertical plane; inwards 60 degrees, outwards 90 degrees, or altogether 150 degrees in the horizontal plane.

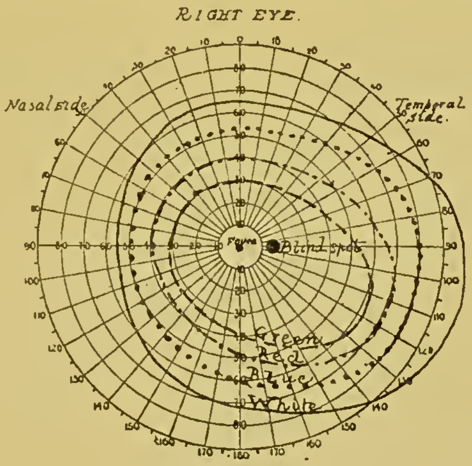


FIG. 26.

The field is limited on the nasal side by the nose, above and below by the brows, cheek, lids, and lashes, while on the temporal side there is no obstruction.

The field is largest for white, blue being nearly the same; then follow yellow, red and green in the order given, each forming an irregular oval (Fig. 26) about 10° less in all directions than that immediately outside it. Colours are barely distinguishable at the periphery of the field—indeed, the outer parts of the retina may be said to be practically colour blind. A coloured object can, however, be seen before the colour itself is recognized, and no matter what its tint may be, if it be bright enough its angular distance is the same as that of white. The fields under which a coloured object can be seen, and under which the colour is recognised, depend on the brightness and purity of the latter, the size of the test disc, and the contrast between it and its background. Examination of the field of vision for white and colours furnish indications of great value to ophthalmic surgeons in the diagnosis of disease.

The Field of Fixation is the greatest angular distance over which the visual axis can be moved, the head being stationary, and it includes the maximum extent of acute vision. The approximate values are up 35°, down 55°, in 45°, out 45°. It is sometimes called the *field of excursion* or rotation. The *total visual field* is therefore practically the sum of the fields of vision and excursion, but this holds good only on the temporal side, where there is no obstruction.

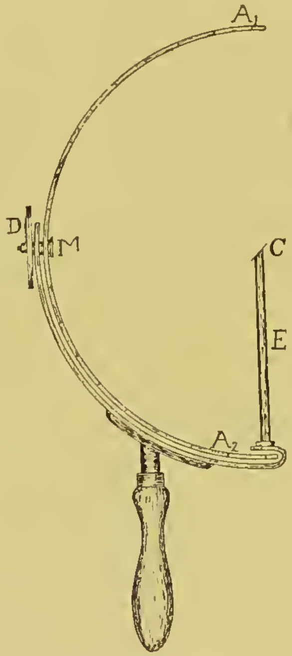


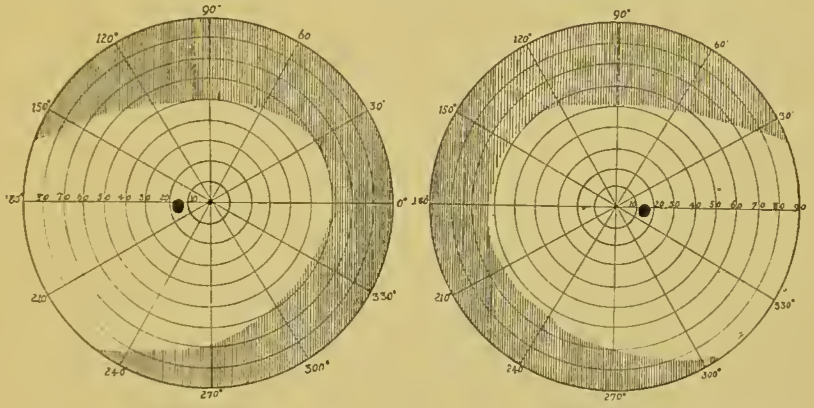
Fig. 27.—The Perimeter.

The Perimeter is employed to measure the fields of vision, rotation or fixation, the size of ocular angles, the angular dimensions of a squint, and to locate and plot scotomata.

The simplest form of perimeter consists of an arc AA' of 180°, whose radius is about 40 cm., and capable of being revolved into any meridian. At the centre of curvature of the arc AA', on the upright E, there is a fixed piece C which rests against the ocular orbit outside and just below the lower lid. The arc is graduated in degrees from zero at M to 90° at either extremity. At M there is a small aperture, white mark, or plane mirror serving as a point of fixation. At D there is a pointer which travels with the arc and indicates, on a dial, the meridian in which the arc lies.

When the eye is at C and directed towards M, revolution of the arc would mark out a hemisphere of which the eye is the centre. In the more elaborate instruments there is usually a carrier on both arms of the arc to which the test object is fixed, and a table for the chart.

To Measure the Visual Field.—The one eye is occluded, and that to be tested is at C and directed towards M; it must not be moved during the test. The arc being horizontal, a small white disc on the carrier is placed at 90° on the temporal side, and slowly moved inwards until it becomes visible; this point is marked. Similarly the field is measured on the nasal side of zero. The two points denote the extreme limits of the visual field in the horizontal meridian, and they should be, very approximately, 90 on the temporal, and 60° on the nasal, side of the visual field. Of course the two sides of the latter are contrary to those on the retina; on the temporal side there is measured the nasal side of the retinal field, and *vice versa*, and this reversal occurs in all other meridians.



Left Eye. Right Eye.

FIG. 28.—SHOWING NORMAL PROJECTED FIELDS OF VIEW AS MEASURED BY THE PERIMETER.

In the same way the field of the vertical meridian, which is normally about 50° above and 70° below, together with those at 45° and 135°, are measured and indicated on paper; or, better, on charts specially prepared for the purpose as shown in Fig. 28, where the shaded spaces indicate the limits of the *projected* normal field of vision of the right and left eye respectively. For an optician who wishes to determine whether there is, or is not, contraction of the field, these four meridians suffice; their limits being marked on the chart, and connected by a curve, the visual field of an eye is roughly mapped out. Even the horizontal and vertical meridians suffice for this purpose.

The field of fixation is measured on the perimeter subjectively by moving a small, well-illuminated letter around the arc so far as it can be distinguished, or a series of figures or letters can be fixed on the arc and read as far as possible. The extent of rotation can be obtained objectively by the reflected pupillary image of a flame when the eye is deviated as much as possible.

For use by the optician, the hand perimeter, illustrated in Fig. 27, is perhaps more useful than the table instrument, but the latter is better for exact work. The trial frame must not be on the face, but the one eye should be occluded by an eye-shade. If there are no carriers the test discs are fixed to a small black plate attached to a long handle, and this is carried around the arc by hand. The white test disc must be kept clean, and there should be also red, green, and other colours.

Scotomata—i.e. gaps in the visual field—are plotted by moving the test disc from the limit point to zero, and noting where it disappears and where it again comes into view. This being done in various adjacent meridians and the limit points marked on a chart and connected, a complete outline of a scotoma is obtained. It must, however, be remembered that there is a physiological scotoma due to the blind spot. The centre of the latter lies n the eye about 15° in and 5° above the macula; it is therefore some 15° out and 5° down on the temporal side of the projected field. The application of the perimeter in the measurement of angle α or κ, or the angular dimension of a squint, is given in another chapter.

Approximate Field of Vision.—The visual field can be roughly measured on a flat surface, such as a large blackboard, at right angles to the visual axis, on which a piece of white chalk marks off on all sides of the axis the tangents of the angular limits of vision. This is sufficiently accurate up to 45°, or even 60°, but beyond these limits it becomes almost impossible, especially on the temporal side where the field is 90°, since tan. 90° is ∞.

In the absence of a perimeter the optician can learn if the field be normal, as follows: The subject fixes the opposite eye of the optician, so that, say, the optician's right coincides with the observed left visual axis; the other eye, of both observer and observed, is occluded. Then, if a small white, or light-coloured stick be moved in different directions in the plane *midway between* the observer and observed, the latter should, if he has a normal field of vision, see it as far, in each direction, as the optician. The procedure is repeated for the other eye.

Law of Corresponding Points.—Every element of the bacillary layer, or at least every cone, has a definite line of projection on which the object point is situated, and on which the mind projects the image point to its position in the visual field. The nasal half of the retinal field of the one eye corresponds to the temporal of the other, and *vice versa*; the upper and the lower portions of the two fields also respectively correspond. The cones being distributed over the retina, the outer terminals of the projection lines form the complete field of vision. The relative position of all points in the field being the same for each eye, the two fields are identical in all respects so far as they overlap. Double vision results if the retinal images do not correspond.

The Binocular Field of Vision.—Most of the upper and lower portions of the fields of vision, and all the central field, are binocular, but a certain portion on each side is seen by the one eye alone. The line of separation between the binocular and the monocular fields is imperceptible, and can be found only by experiment.

In the horizontal visual field (Fig. 29) *ABC*, the central binocular portion, occupies about two-thirds, or 120°, of the entire area of 180°, and is seen by both eyes at the same time. The right and left portions, FN_2K and EN_1H, of the field, about 30° on each side, are less clearly defined, and are seen by the right and left eye respectively.

Fusion of the Fields of Vision.—In order that single vision with the two eyes may result, there must be exact superposition and mental fusion of that part of the field common to both. This is brought about by co-ordinate action of the necessary muscles. Nerve impulses from the brain stimulate the muscles which turn the eyes to the same spot, the action being then yoked. If the object be near, convergence is necessary as well as other muscular action.

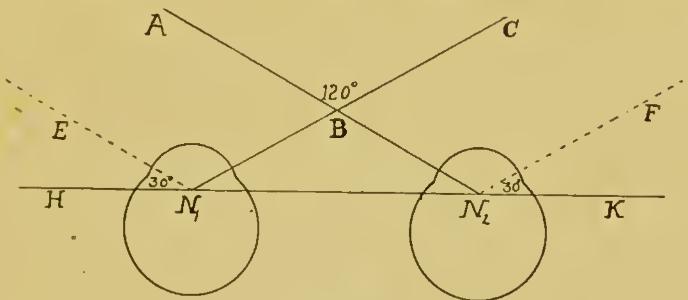


FIG. 29.

Plane of Fusion.—When regarding any near object *O* (Fig. 30), all other points on the median line *DAO*, but nearer or further than *O*, are seen indistinctly. They are also seen double, because their images are neither formed on the two maculæ nor on corresponding points of the two retinæ. The images of the nearer object *A* are crossed, the left image belonging to the right eye, and *vice versa*. The images of the more distant object *B* are homonymous, the left image belonging to the left eye, and *vice versa*.

Although diplopia of this kind is always present, we are unconscious of it. The doubled images are so numerous and so indistinct, compared with the macula image with which one is mentally engaged, that the mind unconsciously employs these double impressions merely to estimate the position of surrounding objects.

Doubleness of Indirect Vision.—That an object in the median plane, and not at the point of fixation, is seen double may be shown by experiment. Thus, if two pencils be held in the median line before the face, the one a few inches behind the other, and the eyes be directed to the more distant one, the nearer one will be seen double; or, if the near one be regarded, the farther one is seen double. In this experiment the double images are seen fairly distinctly, because they are formed at or near to the macular region. A better experiment can be made with a lighted candle held between the eyes and an object, or beyond the latter, when the double flame is very noticeable. When using a rifle, the doubling of the back sight necessitates the left eye being closed while taking aim, unless the right-hand image of the near sight can be ignored, in which case both eyes may with advantage be kept open.

The Horopter.—All things not at the point of binocular fixation are not, however, seen double. Many points in the field besides the fixation point have corresponding retinal images which are fused, although only indistinctly seen.

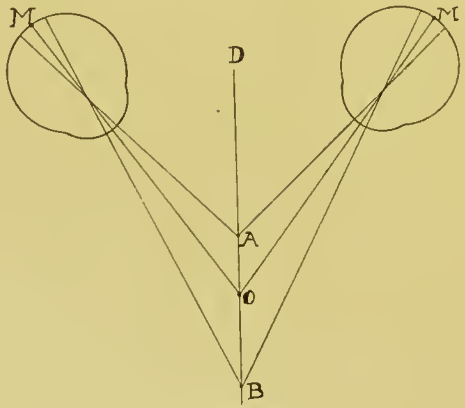


FIG. 30.

Convergence of the visual axes being fixed for a certain point, the locus of all others, seen binocularly as single points, is called the *horopter*. There is some difference of opinion as to the exact nature of the surface of single vision, but the definition of Müller is generally accepted—viz., that it is a circle passing through the nodal points and the point of fixation in the horizontal plane (Fig. 31).

The images of *A* are macular; those of all other horoptic points are extra-macular. If N_1 and N_2 be connected by a chord, and the horoptic circle revolved on it vertically, there is generated the horoptic area, which would seem to be toroidal in curvature. The horoptic circle varies with the inclination of the visual axes to each other—that is, with the amount of Con. in force.

Visual Acuity is the measure of the faculty of receiving, transmitting, and mentally interpreting the retinal impressions. It depends on the transparency of the media, the refractive power of the eye, the nervous functions of the retina and optic nerve, and the interpretive faculty of the brain. Also, to a small degree, it depends on the size of the retinal image, and, therefore, on the distance between the nodal point and retina.

Determination of the Visual Acuity.—The visual acuity is determined by the size of the smallest retinal image which causes the mental perception of parts of an object—*i.e.*, it is determined by the smallest interval between two points or lines, at a given distance, which will permit of these being seen separately and not blended into one. The image itself cannot be measured, but can be calculated, since it is always proportional to the visual angle.

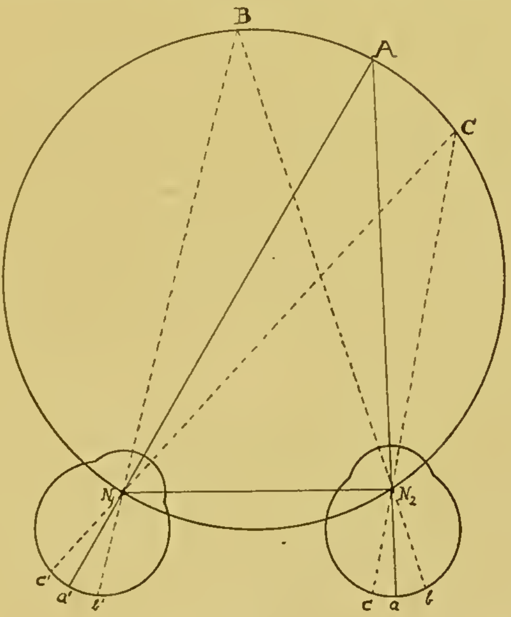


FIG. 31.

N_1 and N_2 are the nodal points of the eyes. *A* is the point of fixation ; *B* and *C* are other points in the horizontal plane on the horoptic circle, and therefore fused and single. *CC'* and *BB'* occupy corresponding points on the retinæ.

It has been found that the smallest object which, as a whole, can be recognized by the *average* normal eye is one which subtends, at the nodal point, an angle of 5′, the details themselves subtending an angle of 1′. This standard is employed in the construction of Snellen types (*q.v.*), which are used for the measurement of visual acuity in practical sight-testing.

The acuity for distant objects is generally greater among savage races than among civilized people, and that of the inhabitants of rural districts is usually better than that of townspeople. Again, the seaman has a better acuity than that of the landsman, and the V. A. varies, in some degree, with nationality. Training and habit account for these facts, because those who are in the habit of constantly using their eyes for distances naturally see remote objects better than those who are not. On the other hand, the more highly civilized and educated races, or persons, generally have a better perceptive faculty for near objects than those who are not so much accustomed to using their eyes for close work.

Lindsay Johnson has recorded cases among the natives of the Upper Congo who could see three of Jupiter's moons with the naked eye. One or two of these natives possessed an acuity four times as high as the usually accepted normal V. A. This was probably due, not to the cones being smaller or closer together at the fovea, but to the crispness of the image accompanying absolute transparency of the media and perfection of the nerve-conducting apparatus, together with entire absence of astigmatism.

Investigations on the refraction and acuteness of vision among people of different ages, classes, and races indicate that a slight degree of hypermetropia, between 0·50 and 1 D., is practically the normal refractive condition, and that those people who have the keenest sight are generally slightly hypermetropic. This degree of hypermetropia may be compared to the fine adjustment of a microscope. Every microscopist knows that he can resolve details better by moving the fine adjustment to and fro while the object is under observation, than he could if the focus, although possibly correct, were fixed and no alteration possible. Now, in low hypermetropia the ciliary muscle allows of this slight play to and fro exactly as occurs with the microscope adjustment.

It has been proved that alcohol and certain drugs temporarily lower the visual acuity, as does fatigue, both of the body generally and of the retina in particular. Thus, a microscopist or astronomer, if he wishes to resolve fine details, such as diatoms or double stars, will be much more likely to succeed if he closes his eyes for a few minutes before looking into the instrument. He will notice further, that after intently gazing through the eye-piece for several minutes, very fine details become blurred, but the sharpness can always be recovered by an interval of rest. A spectrum blue disc, under the stage of the microscope, often prevents muscæ and greatly relieves fatigue.

Limits of Vision.—The limit distance of vision—whether actual or angular—for an object of definite size, is extremely difficult to determine or express. It depends on its luminosity or the amount of light it reflects, the clearness of the atmosphere, the colour of the object—that of its background and the contrast between the two—on the elevation of the object, and curvature of the earth. The distance at which an object can be seen is, of course, very much greater than that at which it can be recognized. The brighter the light from the object, or the greater the contrast of the surrounding field, the smaller is the object that can be seen at a given distance, or the greater is the distance at which a given sized object can be seen. Being more luminous, a same sized white object can be seen at a greater distance than a coloured one.

The distance at which bodies of different colours can be seen varies; generally red can be seen farthest, but the brightness of the colour and contrast are the governing factors. Since it is less luminous, no coloured object is distinguishable so far as a white one. Thus red can be seen only about half as far, and, as a rule, brown is the most difficult of all colours to distinguish at a distance. That the visibility of an object differs with its colour and contrast is illustrated by the fact that a mottled object becomes invisible at a distance at which one uniformly coloured can be clearly seen, the individual patches being too small to occupy non-adjacent macular cones. Apart from other factors, the distance of visibility of an ordinary distant object on a plain or at sea is limited by the curvature of the earth's surface. The distance of the horizon is *approximately* $d = \sqrt{1{\cdot}5\,h}$, where d is the distance in miles and h is the height of the observer's eyes in feet above the earth or sea-level.

An important factor in the perception of objects is that of motion. Thus it is known that many animals render themselves indistinguishable from their background by keeping quite stationary. The wonderful sudden appearance of vultures in the desert is, no doubt, due to their ability to distinguish travellers as moving objects while they themselves, although comparatively near, are invisible in the bright sunlight.

The relationship between size S and distance d for a given visual angle V, is $S = d \tan. V$. Thus if the angle is 1′, an object is seen at a distance 3,000 times its own diameter; if 15″ it is 12,000 times, and so on. Although the recognition of a body depends on its smallest diameter, a long body can be better distinguished than a round one; a thin line can be seen when a point of similar diameter is invisible. A man, to be recognized as such, can be seen under an angle of 5′ or a little less, but the individual parts subtend an angle of about 1′, the distance being about two-thirds of a mile. A white object, without details in sunlight, may be seen under an angle of 30″—*e.g.*, a stone 1 foot square can be seen at about 1 mile. For a round or square body the smallest visual angle, under favourable circumstances, may be taken as 15″ to 25″, and for a line as 3″ to 5″. A bright object, as a minute speck of glistening metal, may be seen under an angle of 1″ or 2″, while a spider web in a bright field, or an illuminated wire, is visible when it subtends an angle no larger than, say, 1/2″.

The ultimate separation of two adjacent points is limited by the distance, 0·002 mm., between the centres of two adjacent cones at the fovea, and there must be a cone interval between the two. But an almost infinitely small body, such as a star, is clearly visible to the naked eye, although the angle it subtends is too small for measurement; it can be magnified by means of a telescope an indefinite number of times, but still has no definite magnitude. The limitations, therefore, in this case are merely dependent on its brightness. All that is required is that the light should possess sufficient intensity to stimulate a nerve fibril in a single cone, and a telescope makes visible an otherwise invisible star by collecting the light from it, and so increasing its brightness. What is seen is the light from the star, not the star itself, so that no impression of distance or magnitude is obtained.

Light Sensation.—It is supposed that the sensation of light is due to the stimulus given to the terminals of the rods, and discrimination between differences of detail to that given to the cones. The cones, however, are much more abundant than the rods at the highly sensitive macula, and, at the fovea, the rods are entirely absent. Moreover, the foveal and macular cones are smaller than those in the peripheral regions; on the other hand, towards the ora serrata, where there is almost complete absence of perception of details, the cones are comparatively few in number; hence the deduction that acute vision depends on the cones, and light appreciation rather on the rods. The fovea is not the most sensitive part of the retina to very feeble luminants or objects of feeble luminosity; these appear to be better seen by means of the rods than of the cones. For instance, a very faint star, invisible at the fovea, can be seen if its image falls a little to one side of it. Many nocturnal animals have few or no cones at all.

Illumination and Visibility.—The visibility of an object increases with the luminosity up to a certain point, beyond which the intensity of the light causes dazzling and confusion from internal reflections and consequent blurring of the image. The effect is increased if the light is very powerful, because a certain amount passes through the iris and sclerotic. One cannot see the sun unless the intensity of the light be greatly modified by smoked glasses, or fog, or otherwise; intensely brilliant head-lights on motor-cars, etc., simply cause confusion, whereas less powerful ones would be more efficacious. A body is best seen if it be sufficiently luminous or illuminated, and in good contrast with its surroundings.

A self-luminous body is seen darker if the surrounding light is more powerful than that of the body; points like stars, which are invisible in the daytime, can be seen from the bottom of a deep well, from which much of the daylight is cut off.

Habit, however, enables a person to see under conditions of illumination which would be impossible for those unaccustomed to them. Even in ordinary circumstances a sudden change from brightness to partial obscurity, or *vice versa*, makes clear vision impossible, as when one passes from bright light into a darkened room, or from the latter to the former, although in a few minutes the eyes, becoming accustomed to the altered illumination, see with sufficient distinctness.

The Visual Threshold.—The lowest degree of visual acuity consists of the bare appreciation of the difference between light and darkness; one possessing less than this is quite blind. The lowest limit of light that can be observed by an eye is termed its *light threshold*, and this varies in different people. It can be represented, for a normal eye, by a piece of white paper feebly illuminated and placed about 200 metres away on a black background.

Fechner's Law.—According to Fechner, the least appreciable increase of stimulus follows a definite law, which holds good for all sensations, and, as regards light, a difference of about 1 per cent. in the intensities of two sources of illumination can be just appreciated. This law, however, only holds true for light of medium intensity. Slight stimuli of any kind are not noticed, so that differences between feeble lights cannot be perceived by the eye at all. Very intense stimuli produce a similar result, for, however much they are increased, no further increment in intensity can be detected. In very feeble, or in very intense, light all things appear equally dark or light respectively.

Measuring the Light Sense.—Forster's photometer, used for this purpose, consists of a box blackened inside and with two openings for the observer's eyes. At the back of the chamber, opposite the sight holes, there is a series of white stripes on the black ground. A light is placed behind an aperture, of variable size, so that the stripes are illuminated to any desired degree. The person to be tested looks through the apertures and gazes into darkness for half a minute or so. The aperture is then slowly opened until the stripes can just be seen, and a scale connected with the aperture shows the degree of light sense. Test-types, or figures, can be substituted for the stripes, and coloured plates can be placed in front of the aperture, so that the light necessary for colour perception can be measured.

The light sense can also be tested by light grey letters, of graduated sizes and shades, on a black background, placed at such a distance that they can just be seen by a normal eye. If the light sense is deficient the letters must be approached in order that they be seen, or it can be tested by a photometer in which two discs are viewed, and the one is made darker by a smoked glass; the smallest appreciable difference in the appearance of the two discs is the *light difference* (L. D.). If a darkened disc be looked at and gradually lightened, the smallest degree of illumination noted represents the *light minimum* (L. M.).

Colour Vision is treated later in Chap. XIV.

CHAPTER IV

PRELIMINARIES TO SIGHT TESTING

Emmetropia—*Derivation.*—εμ, in ; μετρον, measure ; ωψ, eye.

Definition.—Emmetropia is the condition of a normal eye in which the retina is situated at *F*, the principal focal distance of the refracting system, so that, *with Ac. at rest*, parallel light (Fig. 32) focuses on the retinal rods and cones. Em. is that condition in which the static refractive power is proportional to the axial length, and therefore the condition is quite independent of the actual length of the globe. The latter may be longer than usual, with a lower degree of refracting power, or it may be shorter, with a higher degree, and yet be emmetropic. In effect, the Em. eye is one that is slightly hypermetropic, all the hypermetropia being latent. The eye at birth is probably slightly hypermetropic or nearly emmetropic.

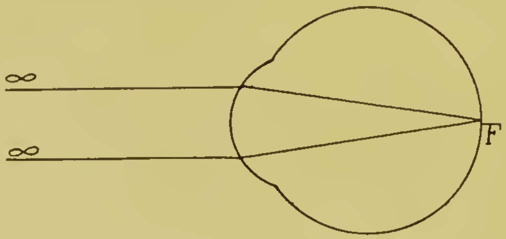


Fig. 32.

From a schematic aspect, the Em. eye may be taken to be 22·2 mm. in length, and the reduced eye, previously described, as 20 mm. The latter, whose posterior focal power is 50 D., will be extensively used for purposes of illustration in the following pages, and in so far as refraction is concerned the eye is then regarded as if it were a lens of 20 mm. focal length.

Illustration of Emmetropia.—The condition of Em. can be illustrated by means of a Cx. lens and a screen. If a + 20 D. lens be held 5 cm. in front of a screen, a sharp inverted real image of any distant bright object, such as a flame or a window, is formed on it. The lens represents the refracting system of the eye, the screen the retina. If the lens be held nearer or farther than 5 cm. from the screen, or if the latter be moved while the lens is kept stationary, the image immediately becomes indistinct. A sharp image is equally well obtained if the lens be weaker and placed farther out, or if it be stronger and placed nearer in, but the image itself is larger in the first case and smaller in the second. The same occurs in the eye if it be longer with less refracting power, or shorter with greater power. The condition of Em. demands that the distance between the principal point and the retina shall be equal to the focal length of the dioptric system.

Ametropia—*Derivation.*—α, without; μετρον, measure; ωψ, eye.

Definition of Ametropia.—If an eye departs from Em., the condition becomes that of Am., of which there are two divisions—hypermetropia and myopia If the eye be too short or its refractive power deficient, the condition is that of H. (hypermetropia), in which, *when Ac. is at rest*, parallel light (Fig. 34) would focus behind the retina. If the eye be too long, or its refractive power excessive, the condition is that of M. (myopia), in which, *when Ac. is at rest*, parallel light (Fig. 33) focusses in front of the retina.

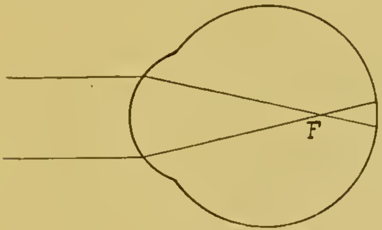


FIG. 33.

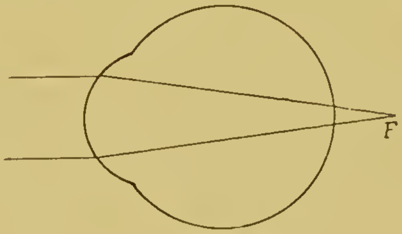


FIG. 34.

Should one or more of the refracting surfaces of the eye depart from true sphericity, then there is As. (astigmatism), which may be regarded as a subdivision of H. and M.

Presbyopia, or deficiency of accommodative action due to age, is not an Am. condition. It can be present in Em. or in Am. eyes.

Compared with that of an adult, the eye of an infant is shorter, but the radius of the cornea and depth of the crystalline are about the same. The latter, however, is of smaller diameter and stronger curvature, so that its increased power compensates for the shorter length of the globe. A baby's eye is normally, therefore, Em., or slightly H. The development of length of globe and diameter of Crys. is concomitant with the growth of the child, the lessened curvature of the lens producing the requisite proportional reduction in focal power. If the proportional increase of axial length is deficient, the eye becomes H., while if it be excessive the eye develops M.

Illustration of Ametropia.—If the + 20 D. lens be held nearer to a screen than 5 cm., the image is indistinct, and the condition represents H. Instead of sharp images of the luminous points from which the light diverges, each cone forms a circle of confusion, and these, overlapping, cause the whole image to be blurred. The refractive power of the lens is too low for its distance from the screen, or, what is the same, the distance is too short for the power of the lens. A similar condition results if the distance between the lens and the screen be maintained at 5 cm., and a weaker lens substituted for the + 20 D. If a stronger lens than 20 D. be used, the light comes to a focus before reaching the screen, and, diverging, produces on the latter a series of circles of confusion, which, overlapping each other, causes a blurred image to be formed. This represents M. The image is similarly indistinct if the + 20 D. be held more than 5 cm. from the screen, for then the lens is too strong for the distance, or the distance is too great for the power of the lens.

Accommodation.—Whatever the precise mechanism of accommodation, the result is the same, viz., an increased total refractive power of the eye. Ac. is always *positive*, and cannot be a *negative* action. When the Ac. is totally relaxed, the eye is then in its condition of *minimum* refraction, and is adjusted for its *far point*. When the Ac. is totally exerted the refractive condition of the eye is at its *maximum*, and is adjusted for its *near point*.

The Necessity for Accommodation.—Light from ∞ is brought to a focus at the retina of an Em. eye in a state of rest; the retina and ∞ are, therefore, conjugate distances. Conversely, if light diverges from the retina, it is parallel after refraction, and the image is, in theory, at ∞. If an object be situated at a finite distance, from which the light is divergent, the conjugate is situated behind the retina, and the image thereon is blurred. In order that the object may be clearly seen, the image must be brought forward to the retina. Thus the refracting power must be increased, which may be brought about artificially by placing a Cx. lens in front of the eye, or naturally by means of Ac. When the latter is exerted, the total refraction is increased to that power having two conjugates, of which one is the retina and the other the point of fixation for which the eye is accommodated.

In visual optics the term *infinity* is commonly, if erroneously, used to denote a distance such that light proceeding from it has an inappreciable amount of divergence, and for convenience we regard 6 m. or 20 feet as complying with this condition.

The Power of a Convex Lens.—A convex lens converges rays from a distant object to a focus at a certain point behind it—*i.e.*, at its focal distance; or conversely it causes light from a certain point—*i.e.*, its principal focus, to be parallel after refraction. For example, a + 5 D. lens brings parallel light to a focus at $100/5 = 20$ cm., or converts light diverging from 20 cm. into parallel beams.

Expression for Accommodation.—Like the power of a Cx. lens, Ac. is expressed in diopters. Formerly, and even in some modern text books, it is represented by $1/f$ where f is the distance of the object viewed.

Calculation for Accommodation.—Since in Em. the distance of the retina is fixed at the focal distance of the static refracting system of the eye, the amount of Ac. exerted for any distance by an emmetrope is calculated by dividing that distance in cm. into 100, or, if the distance be expressed in inches, by dividing into 40. Thus, to see at 50 cm. the emmetrope needs $100/50 = 2$ D. Ac. At 16 in. he needs $40/16 = 2 \cdot 5$ D.; at 70 mm. it would be $1000/70 = 14$ D., and so on.

Conjugate Foci.—If light diverges from a distance d_1, it requires a lens of $F = d_1$ to render it parallel. Again, if the light is to be brought to a focus at a distance d_2, it needs a lens of $F = d_2$. Therefore, if light diverges from d_1, and must be brought to a focus at d_2, the total power of the lens needed is $1/d_1 + 1/d_2$. If we express the distances d_1 and d_2 in diopters, and call them D_1 and D_2, then the power of the lens D is equal to $D_1 + D_2$. This is the essence of the rules of conjugate foci, viz., that the power of the lens is equal to the sum of the powers of any pair of its conjugate focal distances.

If the one dioptral distance D_2 be fixed, as in the case with the retina in Em., then the refracting power needed to bring to a focus at the retina light diverging from any distance is the static refraction of the eye plus the *dioptral* distance of the object viewed. Thus, in order that an Em. eye of 50 D. static refraction may see an object at, say, 100 cm., the power needed is $50 + 1 = 51$ D.; at 25 cm. it is $50 + 4 = 54$ D., and so on. More exact calculations are given in another chapter, but the above simplified method serves for practical work.

Importance of the Conjugates.—Perhaps the most important point to remember in connection with visual optics is that, for any given pair of conjugate focal distances, the refractive power is a definite fixed quantity. Conversely, for a given refractive power and a fixed distance of the one conjugate, the other conjugate can be at one distance only. Thus, if the total refractive power be, say, 54 D., and the retina is at 20 mm. from the refracting plane of the eye, the other conjugate—that is, the maximum distance of clear vision—is $54 - 50 = 4$ D. or $100/4 = 25$ cm. If the distance between the refracting plane of the eye and the retina is less than 20 mm., the other conjugate is farther away than 25 cm., while if the distance of the retina is more than 20 mm., the outer conjugate is nearer than 25 cm. In short, for real foci, as the one conjugate is nearer to the refracting plane the other is farther away and *vice versa*. If the one conjugate be fixed, the other is nearer as the refracting power is greater, and farther away as the power is smaller. The point of vision is *always* the conjugate focus of the retina; otherwise clear vision is impossible at that point and such is the case when, owing to defects of the refraction or accommodation, one cannot see clearly at a certain distance.

The Far and Near Points.—The P. R. (*punctum remotum*), or far point, is the most distant point at which clear vision is possible and is at ∞ in Em.

The P. P. (*punctum proximum*) is the nearest point at which clear vision is possible and this is, usually, a few inches distant from the eye. The position of the P. R. is governed by the refractive condition of the eye, and the P. P. by the combined refraction and Ac. possessed.

Range of Accommodation.—The distance between the P. P. and the P. R. is termed the *range of Ac.*, and is expressed in any terms of linear measure. The range is R – P where R and P are respectively the far and near points expressed in, say, centimetres. Thus, if R = 25 cm. and P = 15 cm., the range is 25 – 15 = 10 cm.

Amplitude of Accommodation.—The quantity of Ac. possessed is termed the *amplitude*. It is the dynamic force necessary to convert the eye from the refractive condition required for vision at the P. R. to that required for vision at the P. P. It is expressed in diopters, so that the amplitude A = P – R where P and R are, respectively, the near and far points expressed in diopters.

The Far Point in Ametropia.—Whether, in Am., the axial length of the eye is too long or too short for the static refractive power, or whether the latter is too low or too high in proportion to the axial length, we may define the two departures from Em.—*i.e.*, H. and M., as follows:

H. is that condition wherein the static refraction is deficient, so that only convergent light, incident on the cornea, will focus at the retina with Ac. at rest. Thus, a hypermetrope of 2 D. has, compared with the emmetropic 50 D., only 48 D. of static power, so that light must converge to 50 cm. or 2 D. behind the cornea in order to focus on the retina. The P. R. in this case is said to be negative or virtual, since it is situated behind the eye. The extra 2 D. of power necessary to render the eye Em. may be supplied either by a + 2 D. lens close to the cornea, or by the exertion of 2 D. Ac.

M. is that condition wherein there is an excess of static power, so that only light divergent from a near object, or rendered so by means of a concave lens, can focus at the retina. Thus a M. of 2 D. has an excess of 2 D. refraction and, therefore, light must diverge from 50 cm. in front of the eye in order to focus at the retina. The P. R. is positive, and a – 2 D. lens placed near the cornea reduces the static refraction from 52 to 50 D. Parallel light refracted by the lens then apparently diverges from 50 cm. which is the P. R. in this particular case.

In any refractive condition the P. R. may be defined as the conjugate focus of the retina with Ac. at rest, and the P. P. the corresponding conjugate when the total Ac. is exerted.

Variations in the Amplitude and Range of Accommodation.—Since Ac. results from resiliency or flexibility of the crystalline, which lessens with age, the Amp. diminishes with advance of the latter. It is generally at its maximum at ten years and decreases gradually through life until, say, at seventy, there is no available Amp. It also to some extent depends on the constant exercise of Ac. The range of Ac. varies directly with the Amp. but is also very largely governed by the refractive condition. Thus with the same amplitude in two different eyes, the range may be entirely different.

Table of Amplitudes of Accommodation.—No statistics of the amplitudes before ten years of age are obtainable, but Ac. can be taken as about the same as at ten or possibly rather less. From ten to seventy years, at intervals of five years, the scale is, approximately, as follows, the near points being calculated for Em.

must be known

Age.	Amp. Ac. in D.'s.	P. P. in cm.
10	14	7
15	12	8
20	10	10
25	8·5	12
30	7	14
35	5·5	18
40	4·5	22
45	3·5	28
50	2·5	40
55	1·5	66
60	1	100
65	0·5	200
70	0	∞

The Amp. of Ac. pertaining to any age, intermediate to those given in the table, can be easily computed.

Range and Amplitude of Accommodation.—In Em. the P.R. is at ∞ and therefore a distant object can be clearly seen without Ac. At ten years of age the Amp. is 14 D., and the range is from ∞ to 7 cm.; at forty years the Amp. is 4·5 D., and the range from ∞ to 22 cm.; at seventy presuming the eye to be still Em, there being no accommodative power, the Amp. = 0. The P. P. coincides with the P. R., and no object within ∞ can be clearly seen.

Significance of the Table of Amplitudes of Accommodation.—The values given do not represent the *average* for any age; much less do they denote the *highest* degrees that may be found. The figures show the *lowest* degree of accommodative power, or the *minimum Amp. that we should expect to find* in an Em. or ordinary Am. eye. As a rule, the Amp. at any age—especially in early life—is considerably higher than that given, and the exceptions where the Amp. is lower are rare. In low H. it is generally still higher than in Em., but in some cases of M., however, more particularly in the high degrees, it is very often considerably reduced, and the same is found in some cases of medium and high H. Convergence and the condition of the motor muscles affect the Amp. of Ac. and, when Am. is present, the *apparent* may differ very much from the *true* amplitude.

The Total Refractive Power in Emmetropia.—Since the *static* refraction n Em. is, say, 50 D., the *total* refraction is 50 D. plus the P. P. expressed in diopters. Thus, if we take the figures of the table given, the total power of an Em. eye at ten years of age is 50 + 14 = 64 D.; at twenty it is 50 + 10 = 60 D.; at forty it is 50 + 4·50 = 54·5 D.; and at seventy it is 50 + 0 = 50 D.

Determination of the Near Point.—If an emmetrope reads clearly at 10 cm., we know he must be exerting 100/10 = 10 D. Ac, and this gives the method of determining the P. P. and the Amp. of Ac. in Em. Fine print is approached towards the eye, and the *nearest point* at which it is clearly seen is measured; this distance is the P. P. and 100 divided by the distance of the P. P. gives in Em. the Amp. Ac. in diopters. Thus if the nearest point of distinct vision is 12 cm., the Amp. = 100/12 = 8·5 D (approx.). This method, in Am., gives only the *apparent*, or *available*, and not the *true*, Amp. Also it is not applicable in old age since then the P. P. is so distant from the eye that fine print is not legible. In the latter case it can, however, be applied by placing in front of the eye a Cx. lens sufficiently strong to bring the P. P. to a measurable distance and then deducting the power of the lens from the dioptric value found. Thus suppose with a + 4 D. lens the P. P. is found at 20 cm.; then the Amp. = 100/20 − 4 D. = 1 D. In Am. a somewhat similar method can be employed, or the eye must be made Em. by means of lenses.

The Near Limit of Vision.—As age increases the accommodative power decreases and when the deficiency of Ac. is so great as to interfere with sustained vision at ordinary near distances, say, 10 to 20 inches, the condition is termed *presbyopia*. There is with everyone a limit to the nearness at which he can do continued near work.

Since the nearest point of distinct vision is regulated by the total refractive power of the eye, which is the sum of the static and dynamic powers, it follows that the nearest point of vision is closer in M. than it is in Em. and farther away in H. with the same Amp. of Ac. If three eyes, of respectively 49 D., 50 D., and 51 D. static refraction, possess 5 D. Ac., the near point will be, in the first case, beyond 20 cm., in the second case at 20 cm., and in the third case within 20 cm. Again, the P. P. would be at the same place in three eyes whose static refraction was respectively 49 D, 50 D, and 51 D, if their respective amplitudes were 6 D, 5D, and 4 D, for then the total refractive power would in each case be 55 D.

Binocular and Monocular Near Point.—It is generally found that the binocular is nearer than the monocular P. P.—*i.e.*, the nearest point of vision is closer when both eyes are used than it is for each eye separately. Such, however, is not always the case and the contrary may occur. It depends chiefly on the balance between the horizontal muscles.

The Absolute and Binocular Amplitude of Accommodation.—The absolute Amp. is that of each eye, independent of its fellow, and is determined by the position of the P. P. when the other eye is occluded, the amount of convergence exerted being then either equal to, greater or less than that required for fusion at the P. P. The binocular Amp. is that of both eyes used simultaneously and is determined by the position of the binocular P. P., the quantity of convergence exerted being that required for fusion at the P. P. of Ac.

The Relative Amplitude of Accommodation is that which can be exerted with convergence fixed for a given distance. It is measured by the difference between the strongest Cx. and Cc. lenses through which vision is clear. If the test be made, as is usual, at 6 m., the Amp. Ac. is relative to Con. = 0. Illustrating this with an emmetrope, it would be found that he could not see clearly through any Cx. lenses at ∞, and if he were able to overcome − 8 D without converging, the Amp. Ac. would be 0 − (− 8) = 8 D. relative to Con. = 0. In H. it is possible that no Cc. lenses could be overcome, so that the relative amplitude is then the difference between the strongest and weakest Cx. lenses through which vision is clear at 6 m. Again, in M., it is not possible, beyond the far point, for vision to be clear with any Cx. lenses and therefore the relative amplitude is the difference between the weakest and strongest concaves. For example, in a given case of H., the test being made at ∞, the limits of clear V., without changing the Con., are with + 5 D. and + 1 D.; then the relative Amp. Ac. = 5 − (+ 1) = 4 D. If, in a given case of M., the limits are with − 2 D. and − 7 D., the relative Amp. Ac. = − 2 − (− 7) = 5 D. In any case of Am., if the manifest error be fully corrected, the procedure is the same as in Em.

The relative Amp. Ac. is never so large as the true Amp. for the reason that Ac. is much more easily exerted in conjunction with Con.; nor is it necessarily the same for all distances.

The Measurement of the True Amplitude of Accommodation is easy in Em. because, the P. R. being at ∞, the position of the P. P. in D.'s gives the true Amp. Ac. whether binocular or monocular. Similarly, in Am., it is obtained from the P. P. if the P. R. is placed at ∞ by means of the correcting lenses.

Primary Angle between the Visual Axes.—In Fig. 35, *AB*, in each eye, is the optic, and *MF* the visual axis from which it can be seen that, if the optic axes are truly parallel to each other, the visual axes, which make an angle of about 5° each with the optic axes, converge and would meet at about 33 cm. in front of the eyes. This distance is obtained from 3/ sin 5° = 3/·087 = 33 cm., where 3 cm. is the semi-interpupillary distance. If the point of fusion of the two visual axes be at 6 m., the angle formed between them is approximately that whose sine is 6/600 = ·01 or 1/2° (approx.). Supposing the angle between the optic and visual axes to be 5°, then each optic axis, when the visual axes meet at 6 m., must diverge some 4·75°, and the total angle between them is 9·5°. Thus when the eyes are adjusted for binocular vision at 6 m., the visual axes slightly converge, and the optic axes diverge nearly 10° from each other. We may, however, neglect the 1/2° above calculated, and take parallelism of the visual axes as the primary position with respect to the subject of Con.

Convergence.—When normally balanced motor muscles are at rest, a single distant object can be fixed by the two eyes and the images, falling on the maculæ, are fused into a single mental impression. In binocular vision of a near object the eyes must be *converged* or turned towards each other, so that the images may still be formed on the macula of each. Convergence results from contraction of the internal, with relaxation, at the same time, of the external recti; were it not exerted, a near object would have its image on non-corresponding parts of the retinæ and be seen double. As before mentioned, Con. is independent of, and can be associated with, any other motor muscular action such as lateral rotation, elevation, or depression of the eyes; indeed, depression is a usual concomitant of Con. since reading, writing, sewing, etc., is always below the level of the eyes. Con. enables vision to be single over any distance between ∞ and a few inches.

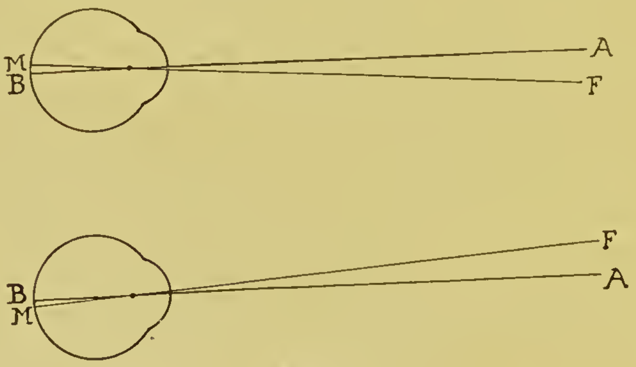


FIG. 35.

Convergence and Interpupillary Distance.—Con. being an angular movement of the eyes effected around the centres of rotation, is measured in degrees. The farther the two eyes are apart, the greater must be the angular movement for fixation and *vice versa;* thus, for any distance of the object viewed, the actual Con. depends on the interpupillary distance.

Expression for Convergence.—It is convenient to disregard the interpupillary distance in this connection, more especially as its variation is small; the actual Con. in degrees is therefore ignored and the function is measured and expressed in *metre angles* (M. A.).

The M. A. is that angular displacement of the one visual axis from its primary position of parallelism when a point, on the median line 1 m.

from the eye, is fixed. It is therefore equal to the angle c (Fig. 36), between the median line $D'F$ and the visual axis RF or $R'F$ and, as the point of fixation F is 1 m. from each eye, *the M. A. is that angle whose sine is half the interpupillary distance, i.e.* $\sin c = RD/RF$. Since half the P. D. (which, in this connection, is considered as being the distance RR' between the centres of rotation) is a fixed quantity, and sines increase less rapidly than angles, the angular value of 2 M. A. is slightly more than twice 1 M. A., and so on. The differences are, however, negligible. Some regard as the M. A. that total angle formed between the visual axes when the point of fixation is 1 m. distant on the one axis directed straight forward. This view is not, however, general and certainly not advisable.

The Value of the Metre Angle varies with the interpupillary distance. If the latter be 60 mm. or 2 3/8 in., the M. A. = 1° 45′ (1·75°). If the P.D. be 64 mm. or 2 1/2 in. the M. A. = 1° 50′ (1·8°). Provided we neglect the difference between sines and tangents, the M. A. can be expressed, in prism diopters, as equal to half the P. D. in cm. Thus if the P. D. = 6 cm., the M.A. = 3$^\Delta$. In other words, a 3$^\Delta$ prism, base out, before one eye in the primary position will cause a Con. of 1 M. A. in order that binocular vision at ∞ may be retained. Approximately the M. A. = 3·5° of prism angle, so that, to convert M. A. to prism values,

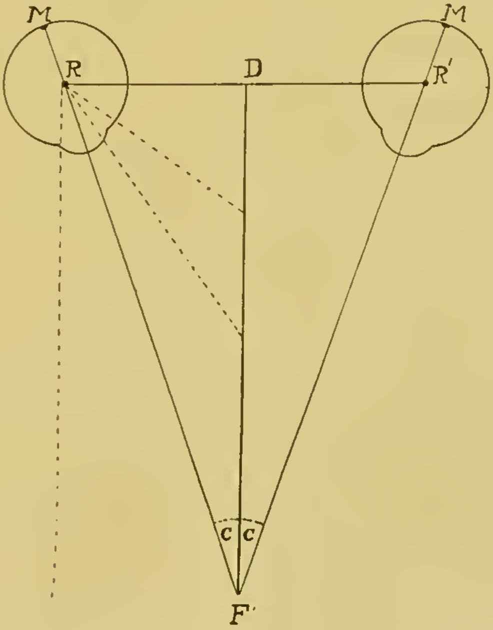


FIG. 36.

M.A. × 1·75 = °d, M.A. × 3 = Δ, M.A. × 3·5 = ° (degrees of prism).

Calculation of Convergence.—For a distance greater than 1 m. less than 1 M. A. of Con. is exerted, while more is exerted for shorter distances. The amount exerted is calculated as for Ac. by

$$\frac{100}{\text{distance in cm.}} = \text{M. A. of Con.}$$

Thus, in emmetropia, the M. A.'s of Con. and the D.'s of Ac. *for each eye* are the same for any distance ; the M. A. was adopted as the unit of Con. in order that it might harmonize with the unit of Ac. For distances expressed in inches, the Con. exerted is calculated by dividing 40 by that distance. Thus at 33 cm. Con. = 100/33 = 3 M. A., at 16 in. Con = 40/16 = 2·5 M. A., and so on.

The Near Point and Far Point of Convergence.—The nearest point at which binocular vision can be retained is termed the near point (P. P.) ; the far point (P. R.) is that at which the visual axes cross when Con. is at rest. The P. P. is usually at a few inches and the P. R. should be at ∞, but more often it is negative since the eyes, when at rest, usually diverge and the visual axes, on continuation backward, meet at the virtual far point behind the eyes. This divergence of the visual axes when Con. is a minimum, must not be confused with the divergence of the optic axes when the visual axes are adjusted for ∞, *i.e.*, parallel. In some cases, of course, the P. R. may be positive and within ∞. The P. P. of Con. is generally within (nearer than) the P. P. of Ac.

The P. P. of Con. is found by approaching a pencil towards the eyes to the nearest point at which it is seen single. The P R. of Con. is found by placing a Maddox groove (*q.v.*) before the one eye and noting the position of rest. It may be that of parallelism, divergence or convergence.

The distance for which the eyes are accommodated is measured from the principal plane and that for which they are converged from the centre of rotation, some 11 or 12 mm. farther back. This difference is, however, negligible in ordinary circumstances.

The Range of Convergence is the actual distance between the near and far points. It usually extends from ∞, or, perhaps, more often from a negative position to within a few inches. The range of Con., or the space over which Con. can be exerted, is expressed by R – P in linear measure.

Amplitude of Convergence.—The total amount of force of Con. that can be exerted is termed the *amplitude*, and is, therefore, the distance between the P. P. and P. R. expressed in M. A.'s; that is, A = P – R. It varies with different people but age has little, if any, effect on it and in this respect Con. differs from Ac.

Average Amplitude of Convergence.—The average person, when exerting Ac., can converge to an exceedingly near point and probably the average

Amp. of actual Con. is not less than 15 or 16 M. A.'s. Some people easily demonstrate 20 M. A.'s although, of course, the point of fixation is indistinct.

Relative Convergence.—This is the amount—positive and negative—that can be exerted when the Ac. is fixed for a given distance. If, for instance, the point of clear vision is at 33 cm., the Con. then found is that relative to Ac. = 3 D. If the test is made at 6 m., the Con. is relative to Ac. = 0.

Measurement of the Relative Convergence.—The relative Amp. of Con. is measured by the difference between the strongest prisms, base in and base out, through which vision is single and clear at the selected distance. That measured by the prism base out is the positive, and that measured by the prism base in, is the negative portion of the relative Amp. Pairs of prisms may with advantage be employed instead of singles. The eyes must converge in order to overcome the − prism (base out), and diverge to overcome the + prism (base in) so that the difference between—really the arithmetical sum of—the two is the total relative Amp. The test may be made at any distance, but in no case is the relative so great as the true Amp.

Measurement of the True Amplitude of Convergence.—This is the difference between the P. P. and the P. R. expressed in degrees or M. A.'s. The P. R. is found as given for relative Con.—*i.e.*, by means of the Maddox rod or other test—and the P. P. from the nearest point of binocular V. when Ac. is freely exerted. For example, supposing the one visual axis shows a divergence for ∞ of 3Δ, and the P. P. to be at 8 cm., the Amp. is $\cdot5 + 12\cdot5 = 13$ M. A.

Orthophoria.—When the external motor muscles are perfectly balanced, *i.e.*, when the visual axes, in a state of rest, are parallel so that the P. R. of Con. is at ∞, the muscles are said to be *orthophoric.*

Esophoria and Exophoria.—The condition of *esophoria* exists if there is a tendency to convergence, the P. R. being positive when the eyes are at rest. *Exophoria* is present if the visual axes at rest diverge, the P. R. of Con. being negative.

Static and Dynamic Convergence.—The term *static* is applied to Con. when the eyes are at rest and it may therefore be positive, negative, or zero. *Dynamic* is positive; it is the physiological muscular process by which the visual axes are so turned that the point of fixation may have an image on both maculæ.

Dr. Maddox divides Con. into three parts, viz.:

1. **Initial Convergence** exerted in order to fix an object at ∞—that is, to render the visual axes parallel. It may be positive, negative or zero, according to the muscular balance.

2. **Accommodative Convergence**, which accompanies Ac., is always positive.

3. **Supplementary Convergence**, or fusion supplement, exerted in order to fuse the images, may be positive, negative or zero.

The sum of 1, 2, and 3 causes the visual axes to meet at a near object point so that single and simultaneous binocular vision results. For distant objects No. 1 alone is necessary.

If the primary position of the visual axes is that of parallelism, there is no initial Con. If the primary position is that of divergence, some positive initial Con. must be exerted in order to see singly at ∞. If the primary position is that of convergence, some divergence of the eyes must be exerted in order that they may fix an object at ∞; the initial Con. is then negative.

When Ac. is exerted it is always accompanied by Con., or conversely, Con. is always accompanied by Ac. The exertion of the two is simultaneous and so naturally associated that it is difficult for ordinary eyes to exert the one function without the other. It is taken that, for each D. of Ac., one M. A. of Con. is also exerted. This is the normal relationship between them, but it is altered by such factors as age, the refractive condition and the balance of the horizontal recti muscles.

Accommodation and Convergence.—On account of a common or associated innervation, or harmony of action, there is an intimate connection between the two functions. If it be taken that neither comes into action for clear binocular vision at ∞, then for a near object both are equally required. For instance, if the object be at 50 cm., there is required 2 D. Ac. and 2 M. A. Con. It is almost impossible to judge which is first brought into action, but probably fixation first occurs, followed almost instantaneously by accommodation.

Combined Accommodation and Convergence.—Emmetropic orthophoric eyes need no Ac. or Con. for ∞, so that the functions are in harmony. So-called Em. eyes are, however, those which would, under complete paralysis of Ac., manifest a slight degree of H. and the usual condition of the muscular balance is that of slight divergence. Thus eyes which, for all practical purposes, are Em. and orthophoric, bring into action a small harmonious exertion of each function for distant vision. In H. more, and in M. less, Ac. than Con. is required for clear binocular vision. Want of harmony as to quantity, therefore, exists in Am. and asthenopia may result therefrom. But real harmony between the functions results when *efforts*, irrespective of *quantities*, are equal, and frequently equal efforts produce unequal quantities.

When the eyes are accommodated for any given near distance, the initial and accommodative Con. then in force may be just that quantity required for fusion of the images and there is no call for supplementary Con. But if the initial and Ac. Con. are insufficient for the distance, some *positive* supplementary Con. must be exerted to obtain single vision. If, however, the former two exceed that amount of Con. needed for binocular fixation, some *negative* supplementary Con. or divergence must be brought into action. Positive supplementary Con. may be required if the initial position is that of divergence, or if less than 1 M. A. of Con. comes into effect with each D. of Ac. exerted. Negative supplementary Con. may become necessary owing to the initial position of the eye being that of Con. or because more than 1 M. A. of Con. results with each D. of Ac.

Association and Dissociation of Accommodation and Convergence.—Normally, equal Ac. and Con. is exerted at all distances, yet the one can be made to exceed the other. At any given distance we can reduce Ac. with Cx., or increase it with Cc. lenses without producing double vision, thus showing that Con. does not conform with the altered Ac. With + prisms we can decrease, and with − prisms increase, Con. without disturbing the clearness of vision, which would occur if Ac. was proportional to Con. Use of one function without the other is, however, painful, but it is comparatively easy to see through − lenses if combined with − prisms, or + lenses with + prisms.

That unequal exertion of Ac. and Con. is the cause of discomfort is shown by the fact that, when Con. is effected, one can easily overcome a *single* Cc. lens by accommodation. Again a person quite unable to view for more than a few moments a near object through a pair of very strong Cx. lenses, has no such difficulty when he closes one eye; in the first case he must converge strongly without accommodating; in the second he uses neither function. Since it is easier to exert Ac. when associated with Con. and *vice versa*, it follows that lenses or prisms can influence the exertions, and so remedy asthenopia.

In low errors of refraction, or low insufficiencies of the muscles, habit usually allows of the one function being exerted without inconvenience in excess of the other—*i.e.*, equal efforts result in unequal productions. In higher degrees either clear or binocular vision may be abandoned to cause harmony and, in such cases, there is generally no asthenopia.

Harmony may be obtained from optical remedies; *e.g.*, Cx. lenses reduce the accommodative effort in H. and Pres., while Cc. lenses increase it in M. + prisms reduce Con. and − prisms increase it. Further, as in orthophoric Em. there may be harmony in exophoric H. and esophoric M. If equal efforts produce a higher amount of Ac. than of Con., it may just suit a given pair of hypermetropic eyes, while the production of higher Con. than Ac. may be acceptable to a certain pair of myopic eyes.

Visual Acuity is the faculty possessed by the brain of interpreting the retinal image of an external object. It depends on various factors, as detailed in the last chapter, but so great a part of this faculty depends on the eye itself that it is both customary and convenient to consider and express it as though depending on the eye alone, the more especially since sight may be, and very often is, better in the one eye than the other.

The visual acuity of an eye is its power to see under the most favourable conditions and, if necessary, corrected by lenses. But in sight testing we must learn and record the unaided vision in order to compare it with that obtained with the optical correction. The latter, and not the former, is the true visual acuity. Therefore, unless it be expressly stated, or unless the context implies otherwise, *vision or V. refers to that of the naked eye*, and is here emphasized in order to avoid unnecessary repetition. The *corrected vision*, when it differs from that of the unaided eye, is referred to as the *visual acuity* and *symbolized by V. A.* Neither V. A. nor V. should be confused with the range of vision, the refractive condition, or any other detail in connection with an eye. Vision may be defective, yet the range considerably above the normal, or it may be normal and the range very restricted. Again, V. may be acute with a comparatively high refractive error, while it may be considerably impaired with a quite low error. Indeed, V. may be much reduced in an Em. eye owing to amblyopia or a nebula.

Expression for Vision and Visual Acuity.—V. or V. A. is expressed by a fraction, of which the numerator d is the distance at which the test is made, and the denominator D is the smallest of Snellen's types legible at that distance. In other words, d is the distance at which the smallest legible letter is recognized, and D that at which that same letter *should* be distinguished by an eye with average normal acuity. In general terms $V. = d/D$.

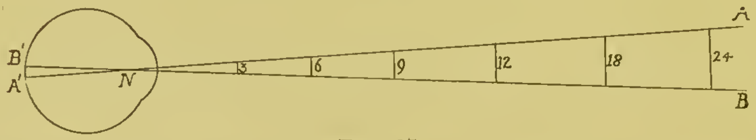


FIG. 37.

ANB represents the visual angle of 5′, subtended by each of the types at its proper distance ; the angle under which the image is formed is the same for all.

Snellen's Types are square block letters so made that the diameter of each part or limb is just one-fifth the diameter of the whole letter. They are employed for measuring the visual powers of the eye. As mentioned in the last chapter, an object, in order to be recognized by a person of *average* normal acuity, must subtend an angle of not less than 5′ at the nodal point, while for two luminous points to be seen distinct from each other, the space between them must subtend an angle of not less than 1′. One letter is distinguished from another by its smallest parts, viz., its limbs ; and it is, therefore, the angle, subtended at the nodal point by the limbs of the letter and the spaces between them, that determines whether it be recognized.

Snellen's types are made for distances varying between 60 metres (200 feet) and 2 metres (6·6 feet) and each size of type is numbered according to the distance, in metres or feet, at which it subtends an angle of 5′ at the nodal point of the eye which sees it. The length of each letter is therefore equal to the arc of an angle of 5′, the radius of which arc is the distance at which the letter should be seen if the eye were at the centre of the circle ;

the diameter of each limb and the spaces between adjacent limbs of the letter are equal to an arc of 1′ on the same circle. The actual series of types and their sizes are given later.

Since object and image subtend the same angle at the nodal point—taken as 15 mm. from the retina—at the latter the arc of an angle of 1′ is 15 × ·00291 = ·0044 mm. The size of a cone at the macula being, say, ·002 mm., the image formed under an angle of 1′ therefore covers about two macular cones. The retinal image formed under an angle of 5′ is ·022 mm. in diameter, the distance between the nodal point and retina being similarly 15 mm.

Distance for Sight Testing.—Vision is usually tested at 6 m. or 20 feet, because light, diverging from this distance to the eye, is presumed to be parallel, or at least to have at the pupil an angle of divergence so small as to be negligible.

For example, suppose at 6 m. No. 12 is the smallest line of legible letters; then V. = 6/12—that is, the eye can only read at 6 m. what one with normal V. would read at 12 m. The numerical expression of V. or V. A. is known as a *Snellen fraction.*

Test Types.—The series generally employed for use at 6 m. comprises the numbers 60, 36, 24, 18, 12, 9, 6, 4·5, 3, 2, or ten lines in all. Since the V. A. is frequently higher than the average 6/6, it is essential that the types be carried below the line numerically equal to the distance employed.

The chart should be artificially illuminated on either side by lamps, behind which are dead-white, unpolished reflectors, to exclude all direct light from the subject's eyes. The form of reflector is immaterial so long as reflection from it is diffuse and gives an even illumination of the types and astigmatic dials. Another small frosted lamp (or a candle) should be placed at the centre of the muscle chart for use therewith.

The types should range from No. 60 *downwards*, so that the smaller letters are more nearly opposite the subject's eyes, the latter being as nearly as possible in line with the centre of the astigmatic dial, below which is the muscle chart. To insure good contrast between the black and white, charts should be perfectly clean and, to avoid regular reflection, they must have a matt, or unvarnished, surface and glass should not be employed as a cover. One or two supplementary type charts are advisable to replace that in ordinary use when a subject becomes familiar with the sequence of the letters; these are better arranged so that only the smaller lines differ. The writer of this article naturally considers the "Orthops" chart the most perfect in design and in the facility with which it furnishes accurate results, and he thinks that those who use it will agree with him.

Jaeger's Types.—For near work a graduated series of ordinary small types, first arranged by Jaeger, is employed, arbitrary numbers being given to them. A person normally should be able to read the smallest (No. 1) at

10 inches, but if sight is impaired he may read only, say, J. 3 or J. 4 at this distance. Types built on Snellen's basis are not available for close work, as people are not accustomed to reading block types, nor are the latter, when small, easy to construct.

Reading Types.—The series should range from the smallest, No. 1 above, to the largest below. No. 3 Jaeger is about the size of ordinary newspaper type. Reading types usually have numbers attached indicating the distance at which each should be legible by an eye with normal visual acuity. In addition there is generally given the power of the Cx. lens with which No. 1 can be read if the type, to which that power is attached, be the smallest legible at the natural reading distance.

Symbols.—It is usual to write O.D.V. and O.S.V., or R.V. and L.V., for vision of the right and left eye respectively; for both eyes the symbols are O.U. or B.E.

Thus O.D.V. = 6/36; O.S.V. = 6/24.

Here the R.E. requires six, and the L.E. four times the normal visual angle in order to see distinctly.

If the test is made at 4·5 m., the V. would be expressed as

O.D.V. = 4·5/36; O.S.V. = 4·5/24.

Some opticians use English measure, the distance being stated in feet —*e.g.*,

O.D.V. = 20/120; O.S.V. = 20/160.

If some letters can be read on a certain line, say No. 18, and others not, it is usual to express the acuity thus: V. = – 6/18, the – sign indicating that No. 18 is seen incompletely. Or it is written V. = 6/18 – 2, which implies that all but two of the letters of No. 18 can be read correctly.

Measurement of Vision.—It is often useful to know V. of both eyes together but, for the purposes of testing and recording, that of each eye separately must be obtained, the one eye being occluded by the opaque disc and the subject directed to read the Snellen's types downwards until he arrives at the smallest legible. Binocular V. is nearly always better than that of one eye only. If no types on the card are legible, that is, if V. is less than 6/60, it is recorded thus: V = <6/60. It may be roughly determined by the greatest distance at which fingers can be counted, these being about the same diameter as the limbs of No. 60. The optician approaches with his hand extended and if fingers can be counted at, say 2 m., then V. = 2/60; or the subject can slowly approach the chart and the greatest distance at which the top letter is read gives a similar result. When V. is much lowered, there may only be P. L. (perception of light), or H. M. (hand movements). If a client is illiterate or dumb, V. can be obtained from an *illiterate* chart, a good form of which consists of series of block E's graduated in size and turned in different directions. The subject states, or designates by signs, the direction of the limbs of the letters. For very young children, a useful chart is one consisting of different animals or objects constructed on the Snellen basis, as designed by Dr. Ettles.

Vision should be tested with the types fully illuminated and for this purpose artificial light is preferable; otherwise V. would vary on different occasions, as for example on a November afternoon and a July morning. Care should be taken that the subject does not partially close the lids, since this, by cutting off peripheral rays, improves the sight and gives a wrong estimate of V. Nor should he look obliquely through a trial frame past the edge of the cells, which would have a similar effect. In all circumstances the eye should only be occluded by the opaque disc and not by the hand of the subject or of the optician himself.

The expression of the unaided and corrected vision would be made thus:

$$\text{O.D.V.} = 6/60 \text{ with } -2{\cdot}0 \text{ S} \subset\!\supset -1{\cdot}0 \text{ C } 180 = 6/4{\cdot}5$$
$$\text{O.S.V.} = 6/36 \text{ with } -{\cdot}5 \text{ S} \subset\!\supset -2{\cdot}0 \text{ C } 180 = 6/4{\cdot}5$$

indicating that the unaided subnormal V. is raised to 6/4·5 by the lenses mentioned.

Normal Vision.—If V. or V. A. = 6/6, it is said to be normal, because at 6 metres one can distinguish those letters representing the average degree of sharp vision. Many people have a visual acuity better than 6/6—viz., 6/4, or even 6/3; they can distinguish objects and their details under angles smaller than 5′ and 1′. Nevertheless many insist that normal vision is a fixed fraction, *i.e.*, 6/6. The author does not agree with this view but considers it a variable quantity subject to various influences and that V. = 6/6 is only the *average* normal vision, the fraction being, in many cases, too high and, in some cases, too low to be taken as the standard needed to be reached in corrected ametropia.

Normal vision, up to a certain age, is represented by 6/4; with advance of age, 6/6, 6/9 and 6/12, might be regarded as normal for people at, say, 60, 70, and 80 respectively. The reason why the visual acuity is better in young than in old people is the transparency of the media, some of which is lost in old age. Moreover, the physiological activity of the retina and optic nerve is more acute in youth, and in old eyes there is generally some degeneration of the choroid which, in an advanced stage, becomes a senile choroiditis. Conversely a reduced visual acuity in old age is as normal a condition as decreased accommodation and refraction, and it is this fact, together with variations due to education and environment, that renders necessary the use of such a term as *unduly subnormal vision* when the visual standard is taken as a *fixed fraction*.

The visual acuity, as expressed by a Snellen fraction, varies with environment—whether rural or urban—with the health of a person and also to a great extent with the nature of his occupation and food. It varies further with the education and alertness of the individual—with the brain or intelligence behind the eye—so that what would be taken as average normal visual acuity in the out-wards of an East End hospital could not be so regarded in the consulting-room of a West End oculist; mental torpidity and illiteracy may account for several lines on the test types. Further the degree of illumination, the whiteness of the background, and the blackness and sharpness of the types, influence the fraction which expresses the V. in any given case. In addition it is important to remember that some people, especially children, will state that they cannot read certain small types, and yet will correctly name each letter if the latter be specially indicated by a finger or pencil; apparently a mental stimulation is derived from the individualization of each letter, the attention not being allowed to wander over the whole series in a particular line.

To avoid repeated reference to what constitutes normal vision it is taken throughout to be as defined in the first paragraph of this article. Experience alone will enable the optician to know what Snellen's fraction to accept as normal in any particular case. The conditions under which V. and V. A. vary in Am. are discussed in the chapters on individual errors of refraction.

Reduced Vision.—It is sometimes stated that 6/12 represents half normal vision, 6/18 one-third, and so on. One who has actually only half normal vision is practically half blind, which is far from being the case when V. = 6/12 owing to a simple error of refraction such as axial myopia. In the latter case the refracting media are perfectly transparent, the retina and the nerve-conducting apparatus quite normal, and for all practical purposes the person sees his way about and performs his work nearly, if not quite as well, as one who has full visual acuity. If V. is, say, 6/12 and can be raised to the normal with correction, the condition of sight, *without lenses*, is incomparably better than that in which the best V., obtained *with correction*, is 6/12. This is a matter of great importance to the optician and should be thoroughly grasped.

Further, if one has no better vision than V. = 6/12 when fully corrected for his optical defect, much still depends on the cause of the deficiency. Should the reduction of vision be due to a defect of the media, such as conical cornea, nebula or the diminished transparency of old age, the sight is much more useful than an equal reduction, as measured by test types, due to a diseased condition of the choroid or retina, or a partial atrophy of the optic nerve. In the former case the nervous apparatus is perfect but the media do not allow of sharp retinal images, while in the latter case nervous response does not follow the stimulation of the image, however sharp it may be.

The Determination of Emmetropia.—If V. is normal and the application of a weak + sph. blurs the sight—*i.e.*, makes V. worse—Em. may be presumed. In this condition parallel light, proceeding from the various points of a distant object, is focussed sharply at the retina without the exertion of Ac. The weak + sph. places the image slightly in front of the retina, with the result that the image consists of small diffused circles, instead of point foci, and vision becomes less acute. The weak + lens simply makes an Em. eye slightly M. As previously mentioned an Em. eye is probably one having a small degree of H. all latent and, for practical purposes, further reference to Em. will mean that condition where normal V. becomes impaired by a weak + sph. lens, together with a near point consistent with the age of the individual. It is the condition of the eye which is manifestly, if not actually, Em.

The Determination of Ametropia will be found in the chapters devoted to each.

The Measurement of Ametropia.—The optician must constantly bear in mind that he can measure only the *manifest* condition; sometimes the manifest and the actual refractive errors are equal and, anyhow, in the large majority of cases the manifest only need be known in order to prescribe lenses giving good and comfortable sight. Should the test indicate considerable latent error, the case should be corrected under the influence of a cycloplegic, and therefore by, or under the direction of, a medical practitioner. Cases requiring cycloplegia are generally found in very young people; sometimes, also, later in life where high H., high As., or strabismus occurs, but they are comparatively rare after twenty years of age.

The optician may conscientiously prescribe lenses only when there are *normal visual acuity* as previously defined, *normal field of vision* and *absence of contra indications.* In all that follows concerning the testing and correction of refractive errors, adherence to this rule is presumed.

Order of Testing.—Either the right eye should always be first tested, or the rule may be adopted of treating first that with the worst vision, because an eye markedly inferior as to its vision, is generally less easy to correct than the other, and it can receive further attention after the better and easier eye has been tested. The correcting lens is placed as near as possible to the cornea—approximately in the anterior focal plane; thus situated, a Cx. lens corrects more H., and a Cc. less M., than its nominal power. Further, the true degree of error may be between two successive trial case powers, this being especially noticeable in As.

Systematic testing, which is the secret of success, is more thoroughly dealt with in Chapter XII., but the order is roughly as follows—

Determine separately of each eye (*a*) the unaided V., (*b*) the manifest refraction, (*c*) the corrected V., (*d*) the P.P., (*e*) compare the V. A. and P. P.

of the two eyes, (*f*) determine the muscular balance. Having decided on the lenses to be prescribed, the frames are selected and fitted.

Tests may be either *subjective* or *objective*, but the latter should always be carried out prior to the former. Objective methods, of course, render the refractionist independent of the subject's answers and include keratometry, retinoscopy, etc., which should be employed first, even perhaps before the V. A. has been taken. The subjective test, being by far the most important, comes last in order to confirm and supplement the results obtained objectively. Sight can be tested perfectly well by subjective methods alone, but not so objectively, as it is unlikely that the correction so found would be the best obtainable.

Complicated Cases.—It is advisable not to prescribe glasses from a single test in a complicated case. The result of the first should be entered, and confirmed or altered, as the case may be, at a second or even a third test, before lenses are prescribed. Temporary spherical lenses may sometimes, with advantage, be given in the meantime. Such cases include previously uncorrected high errors of mixed As., high anisometropia, spasm of Ac., high heterophoria, etc., together with those not relieved by glasses fitted by others, and those in which fatigue renders the results obtained uncertain.

Distance of Chart.—To determine the static refraction, Ac. must be passive or active only to a negligible degree and therefore, as explained in a previous paragraph, 20 ft. or 6 m.—to be found in a fair-sized room—is taken as sufficient, the divergence of light, on reaching the eye, being then only ·16 D. In case of necessity, 4·5 m. will serve, as the Ac. used in Em., or by the corrected ametrope, for that distance, is less than ·25 D. If a room will not admit of even 4·5 m., it is better to employ reversed types and a mirror so that the total distance from the types to the mirror and thence to the subject is 6 m. Preferably, for this purpose, each should be 3 m. The mirror should be exactly half the size of the chart in both length and breadth, so that the image of the latter just fills the former, the frame of which should be plain and black.

The Reading Distance, governed mainly by the height, or length of arm of the individual, varies between 25 and 50 cm., the ordinary reading distance being 40 cm.; it is that between the eyes and a book held in the hands when the arms are bent to a right angle. The distance of other work, as writing, is greater than that for reading, but reduced V. A., from whatever source, may cause the working point to be closer.

Points on the Testing Room.—None other than the types, the astigmatic, and the muscle charts should be placed on the wall facing the subject. The illumination for the hand types should be obtained from an adjustable bracket placed behind the test chair; this also serves for focal illumination, retinoscopy, etc. The test room should also be provided with ordinary illumination capable of being easily lowered, or put out. Electric light is preferable, the various lamps being governed by a switchboard near to the testing chair. The colouring of the walls and floors should be subdued and of uniform tint. Dark browns and greens are serviceable, but any scheme of decoration may be followed provided it is unobtrusive. The test chair is preferably placed on a small platform about 1 ft. high, so that the subject, when seated, has his eyes but little below those of the optician. Useful accessories in a test room are needle and thread and a piece of cotton material for sewing, a sheet of music, a Prayer-Book in fine type, etc.

3 3

6

20.H

The Test Case should contain a series of pairs of Cx. and Cc. sphericals up to 20 D., cylindricals up to 6 or 7 D., prisms in pairs up to about 3Δ, and singles to 20^{Δ}. The dioptic intervals in the lenses should be ·25 up to 3·5 D., ·50 from 3·5 to 8 or 10 D., 1 from 10 to 14 D. and 2 between 14 and 20 D. The lenses should be mounted in rings with handles, which, besides greatly facilitating their employment, renders them less liable to soiling. Some obvious distinction should exist between the convex and concave series, both spherical and cylindrical, to prevent mistakes. For preference the convex lenses should be ringed in white metal or nickel, and the concaves in gilt; or the handles may be different. Cylindricals are generally partly frosted and are thus easily recognized. The axis marks of cylindricals and the base apex line of prisms should be sufficiently long and distinct. The complete case also requires certain discs and coloured glasses, the latter preferably in pairs; the use of some of the various discs, as well as other sight-testing accessories, are detailed in the following paragraphs, but others are dealt with in due course.

In many modern test cases the strong Cx. lenses—those from 10 D. to 20 D.—are weaker than their nominal powers, their actual powers being those which neutralize Cc. lenses of corresponding numbers. The difference between the actual and nominal powers varies from about ·16 D. for + 10 D. to 1·16 D. for + 20 D., the thickness of the Cc. lenses being taken as 1 mm. and that of the Cx. varying between about 4 and 8 mm. at the centres.

The Trial Frame, for general use, should have three carriers for each eye and should be adjustable for P.D. Ht., Proj. and length of sides, if the latter be curl. Straight sides are, however, better and, generally, a frame with spring cells is most convenient but some prefer the *drop* style. It is advisable to have more than one trial frame and they may be of different patterns. A light drop frame, that will hold securely two lenses for each eye, is useful if one wishes to try how a certain combination serves in use, and such a frame is the best for retinoscopy. All frames should be scaled in standard angle notation. Lightness, adjustability and rigidity are the points to look for, but the ideal trial frame has yet to be made. Adjustability is necessary to bring the optical centres of the lenses before the centres of the pupils, and thus avoid prismatic effects. Scales on the frame, for taking facial measurements, are of little practical value.

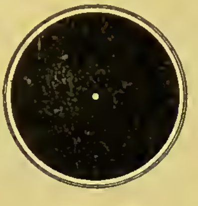


Fig. 38.

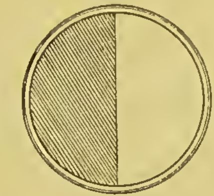


Fig. 39.


Fig. 40.

The Opaque Disc is made of vulcanite, metal or frosted glass, and serves to occlude the one eye while the other is under test. An extra opaque disc with a long handle is also useful.

The Pin-hole Disc is a vulcanite or metal plate having a small aperture in the centre. The case should contain two such discs, one with a fine perforation about ·5 mm., and another about ·75 mm. in diameter (Fig. 38).

Fig. 41.

The Half-Opaque Disc.—This is occasionally useful for determining which half, or portion of the eye—as in conical cornea, nebula, irregular As., etc.—is the most useful for visual purposes (Fig. 39).

The Stenopæic Slit or Disc is for determining and testing As. It is desirable to have two of these discs—the one of fine aperture about ·5 mm. in width, and the other larger of about ·75 mm (Fig. 40).

Fig. 42.

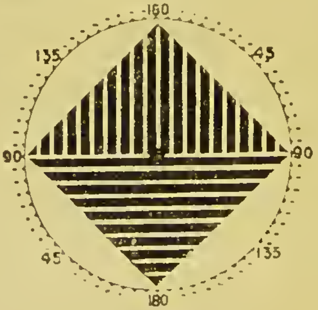


Fig. 43.

The Muscle Chart, which consists of a central pointer having red figures on the one side and green on the other, is required for testing the muscular balance. The spaces between each figure represents 1△ at 5 or 6 m. (Fig. 41).

The Astigmatic Fan and Dial.—The former is a fan of pairs of lines radiating in different directions over half a circle or more. They serve to determine As. and to indicate roughly the principal meridians. The dial, or diamond, consisting of two series of lines lying at right angles to each other, can be revolved to indicate more exactly the principal meridians and is used for the correction of As (Figs. 42 and 43).

FIG. 44.

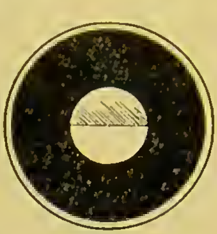


FIG. 45.

The Maddox Rod, the Maddox Groove, and Double Prism, are employed for testing muscular imbalance (Figs. 44 and 45).

Red and green glasses are employed for distinguishing the image seen by one eye from that of the other.

The Placido Disc serves for determining objectively the presence of regular and irregular corneal As. (Fig. 46).

The Near and Far Points Measure is used for determining the P. R. and P. P. and therefore, also the refractive condition of the eye and the amplitude of Ac. The "Orthops" pointer (*q.v.*) is the simplest and most useful form.

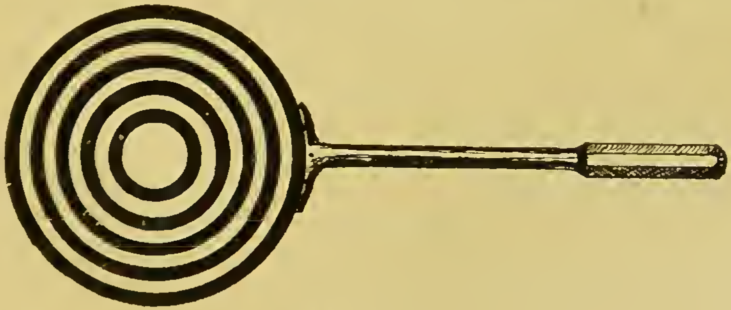


FIG. 46.

The Condenser is a large Cx. lens of about 3 in. focal length for examining the cornea, iris, etc., and for use with the ophthalmoscope in the indirect method.

In addition there are the **Face and Frame Rule, the Record Book, and Prescription Forms.**

The foregoing comprise the essential adjuncts to the test case for the complete practice of subjective testing. Various other instruments, mainly objective, of which the following are the most important, may be added at discretion :

The **Ophthalmometer**, an instrument for measuring corneal As.; the **Perimeter**; the **Retinoscope** and **Ophthalmoscope**.

Records must be systematic, and are best kept in a book which is indexed from time to time, each record being numbered in succession.

The necessary details comprise:

1. Date.
2. Name, address, occupation and age.
3. V. of each eye, separately, without glasses.
4. The correction found, representing the manifest optical condition of each eye.
5. Corrected V. A. of each eye.
6. The P. P. of each eye corrected.
7. The muscular balance.
8. The lenses prescribed for distance, constant wear or reading.
9. Particulars of the frame.
10. Price charged.

Nos. 1 and 2 are at once entered, but many people, especially women, take ungraciously a question concerning age, being perhaps unaware that it is an essential detail; the question may be left until later and put guardedly. As soon as they are learnt the other details are entered in the spaces reserved for them in the record book.

Further data that may be required are:

Glasses previously used, and by whom prescribed.

Added presbyopic correction.

Apparent P. P. of each eye without lenses.

Apparent P. R.

Apparent Amp. Ac.

Ophthalmometric or other objective tests.

The medical man to whom a case is referred and why.

Other points which may present themselves as worthy of record.

If the test is made by different methods, for instance, by retinoscopy and by test lenses, the result of each should be separately entered so that they may be compared. This also should be done with tests made on different occasions, the dates being appended.

Value of Records.—A customer is generally glad to know that, in case of loss or breakage, the glasses can be replaced without, of necessity, the sight being again tested or fresh frame measurements taken. He is also the more likely to return after an interval, when he requires new glasses, to where he knows that a record is kept. When a customer returns, even after years, it is extremely useful to be able to note any refractive or muscular changes and his record should be easily got at. Records form a tangible asset to the established optician. The more there are and the better their indexing, the greater is the value of his connection.

The Writing of Prescriptions is a work to which due attention should be given. Many opticians give so many details concerning the frame that the manufacturer finds it difficult or impossible to dovetail them; necessary details only should be given and unnecessary ones carefully avoided, they being left to the manufacturer. It is a common oversight to omit the + or − sign, or to misplace or omit the decimal point, or to omit the position of the axis of the cylindrical. Prescriptions should preferably be written on proper printed forms.

If, as it should always be, standard notation is employed, the numerical positions of the axes suffice, but for any other notation a line drawn through a notated half circle on the printed form should be given in addition. A designation of so many degrees up and in or down and out is impossible of exact interpretation, and should, therefore, not be used.

Oculists' Prescriptions should be duly filed, or the details entered systematically in a book kept for the purpose, particulars of the frame and prices charged being added to those given on the ℞. Medical men, as a rule, leave to the optician the fitting of the required frames. If the ℞ has the cyl. axes indicated in other than standard notation, care should be taken to accurately transcribe it, or to indicate the position so that the manufacturer cannot make a mistake. Unless permission be given, it is better not to transpose the lenses ordered.

CHAPTER V

HYPERMETROPIA

Derivation.—υπερ, beyond ; μετρον, measure ; ωψ, eye.

Definitions.—Hypermetropia, or hyperopia (Fig. 47), is the condition of an eye in which, when the Ac. is suspended, parallel light would come to a focus behind the retina, the latter being situated within the principal focal distance of the refracting system. H. is therefore that condition in which the P. R. (*i.e.*, the conjugate focus of the retina) is negative and situated behind the eye, as shown in Fig. 48.

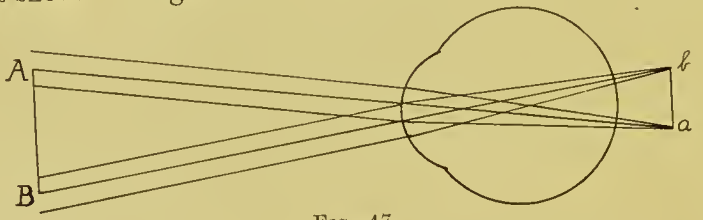


FIG. 47.

H is illustrated when a screen is placed within F of a Cx. lens. Parallel light refracted by the lens meets the screen before a focus is formed; light diverging from the screen emerges from the lens divergent as if proceeding from a point behind the screen.

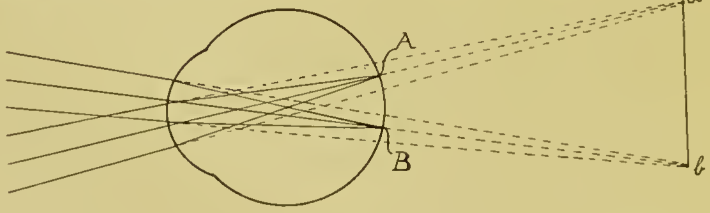


FIG. 48.

Causes.—The foregoing condition can result from the eye being too short axially, while the refracting power is normal, or from the length being normal while the refracting power is deficient. The former is termed *axial*, and the latter *refractive* H. In both cases the focal length is greater than the distance from the principal point to the retina. H. does not exist solely because the refraction is deficient *or* the eye is too short, but because the refraction is deficient for the length or the length deficient for the refraction.

Age of Appearance.—It is commonly said that H. appears at birth, but as a condition requiring treatment on account of pain or difficulty in vision, it may manifest itself at any period of life.

Prevalence.—True Em. is so rare that, excluding those actually myopic, practically all eyes are hypermetropic. Further, an eye Em. in middle life may not have been so in childhood and does not remain so in old age. Again those which are Em. when the Ac. is completely paralyzed, as by a cycloplegic, are not under ordinary conditions and *vice versa.* Since only a comparatively small proportion of people are M., it follows that the great majority are H.

H. Congenital and Acquired.—We say that H. is *congenital* or *original* because the shortness of the globe is not acquired. Whatever the refractive condition of the eye at birth, and this is probably slightly hypermetropic, the acquirement or not of H., as found later in life, depends simply on the axial development with relation to the focal power. Thus, in a sense, H. is acquired although it is a condition of insufficient development. It is also often hereditary. True *acquired* H. is described in another article.

Refractive H. may result from an abnormally low curvature of the cornea or crystalline, and is then termed *curvature* H. Or it may result from (*a*) a low index of refraction of the cornea and aqueous, (*b*) a high index of the cortical layers of the lens, (*c*) a low index of the nuclear portion of the lens, (*d*) a high index of the vitreous. With the exception of *b*, which will be referred to later, none of these conditions of altered refractive indices are demonstrated in a healthy eye. Curvature H., due to the cornea, is also sufficiently rare and indeed the H. eye is more likely to have a cornea of slightly greater curvature than is found in Em. We do not assign *original* H. to the influence of the crystalline.

Axial H.—Shortness of the globe is the common cause and, in this condition, the refractive power—and, therefore, the focal lengths—are *presumed* to be the same as in Em. but the receiving screen—*i.e.*, the retina—lies in front of the posterior focal plane.

The Degree of H. varies from one so low that it is regarded as Em. to that known as *microphthalmos*, in which the eyes are very small and ill-developed.

The Optical Condition.—Although H. is almost always due to abnormal shortness of the globe, yet it may be conveniently regarded as one of insufficient refracting power. Thus if the power of an Em. eye be 50 D., that of an H. eye is less. An eye H. 3 D. can be taken to be one whose refractive power is only 47 D., there being a deficiency of 3 D., which could be corrected by means of a + 3 D. lens. The power of the correcting lens added to that of the eye makes the total power equal to the normal. The condition of H. is *negative*, the same as if a Cc. lens were placed in front of an Em. eye; the correction or neutralization of the defect is a positive or + lens, just as the − lens in front of an Em. eye, which produces an artificial H., would be neutralized by a + lens of equal power. The strength of the correcting lens expresses the degree of optical deficiency or error.

Accommodation in H.—If V. is normal there is constantly exerted, for ∞, Ac. equal to the dioptric expression of the total H. Thus in H. 1 D. or 3 D. there is exerted for ∞ respectively 1 D. or 3 D. of Ac. For all distances nearer than ∞ the H. exerts as many D.'s of Ac. *more*, than does the Em., as there are D.'s of H. For instance, in Em. for seeing at 40 cm. Ac. = 2·50 D., in H. 1 D. for that same distance Ac. = 3·50 D., and in H. 3 D. there are exerted 5·50 D. and so on. In H. fully corrected by lenses, the exertion of Ac. is the same as in Em. In H. partly corrected by lenses the exertion of Ac. exceeds that of Em. by the amount of H. left uncorrected. Thus in H. 3 D. with a + 2 D. lens the Ac. action would be as in H. 1 D.

Convergence, as expressed in M. A.'s, is the same in H. as in Em.

Ac. and Con.—If there is clear binocular vision, Ac. must always be exerted in excess of Con. in uncorrected or partially corrected H. Thus in H. 3 D., for ∞, Ac. = 3 D. and Con. = 0; at 50 cm. Ac. = 5 D. and Con. = 2 M.A. If the H. were partially corrected by a + 1 D. the Ac. exceeds Con. at all distances by 2 units. Only if the H. be totally corrected by a + 3 D. lens are the functions equal as to quantity.

Divisions.—H. is divided into *manifest* and *latent.* Manifest H. is that portion of the defect which is apparent and measurable by means of Cx. lenses. Latent H. is that which is hidden by accommodative action and cannot be measured by Cx. lenses, unless the eye is under the influence of a cycloplegic. The manifest plus the latent is the *total* H.

H. can be further classified as *facultative*, *absolute*, and *relative.* Facultative H. is that neutralized or corrected by Ac. action. Absolute H. is that not neutralized by Ac. action. Relative H. is that which becomes facultative by squinting. Relative may be present at the same age as either of the others, the squint being periodic. The facultative plus the absolute also is equal to the total H.

The terms *facultative* and *absolute* are sometimes applied to express the conditions of H. in which V. is, respectively, normal and subnormal. That is, they express general conditions and not, as above defined, definite parts of the total H. As here defined, there may be facultative and absolute H. in the same eye at different periods of life or even at the same period at different moments.

Manifest H.—In most cases with young people where Ac. is active, the exact degree of manifest H. is difficult to determine, since the amount of Ac. exerted, and consequently the V. obtained with a certain lens, fluctuates from moment to moment. Manifest H. may be partly *absolute* and partly *facultative.*

Latent H.—All hyperopes, unless so old as to possess little or no Ac., exert that function in distant vision and it does not entirely relax on the application of Cx. lenses; in other words, the ciliary muscle acquires a permanent, but perfectly normal, cramp. Such portion of the H. as is thus masked is termed *latent* and it is, of course, also facultative. It can be made manifest only by the application of a cycloplegic, which may cause a portion of it to become permanently manifest. A similar result may be obtained by *fogging* (*q.v.*). The presence of latent H., and its approximate degree, can be sometimes determined by the position of the P. P.

Total H.—Until late in life, the total H. is usually partly manifest and partly latent and the proportions vary very considerably in different eyes, and in the same eyes at different periods of life. The proportion of latent is governed chiefly by the amount of Ac. possessed which again depends greatly on the age, and by the smallness of the total error. In young people and even up to, say, 30 years of age a low degree of H. would probably be all latent. Indeed, as previously stated, such a refractive condition is regarded as Em. Very late in life H. must become all manifest, as there is then no Ac. available for the purpose of neutralizing the refractive error. In general, the higher the total H. the smaller proportion of it is latent. Thus if, at any given age, the total error is 1 D., it may be all latent, if 3 D. it may be half latent, while if 6 D. probably not much more than one-quarter of it would be latent. As a rough approximation in medium degrees of, say, 2 D. to 4 D. total H. which is facultative we may assume that at 10 years of age 3/4, at 20 years 1/2, at 30 years 1/4 or 1/3 is latent, and at 40 years all is manifest. This approximation can be expressed by

$$\text{Hl.} = \frac{\text{Hm. (40–age)}}{\text{age}}.$$

In some cases a latent error is found later than 40.

Facultative H.—That portion of the H. which is masked by Ac. action is termed *facultative.* If V. is normal the H. is all facultative, of which part may be manifest and part latent. The latent is facultative, the manifest may be so or not. Usually low degrees of H. are wholly facultative, as it is easy for one possessing a large amplitude of Ac. to use, for distance, sufficient to supplement the deficiency in the static refractive power, and there is usually simultaneous binocular vision.

Absolute H.—When Ac. cannot be exerted to an extent sufficiently great to bring parallel light to a focus at the retina V. is subnormal, and the term *absolute H.* is applied to that portion of the defect which the Ac. cannot correct. As a rule, in high degrees part of it is absolute ; the lower degrees, which early in life were facultative, become partly or wholly absolute as age advances and the Ac. amplitude becomes smaller and smaller. Absolute H. is, of course, also manifest, and, under cycloplegics and in extreme old age, the H. is therefore totally absolute as well as totally manifest. With absolute H. there may be simultaneous binocular vision, alternating binocular vision, or monocular vision.

Relative H.—When vision of one or both eyes becomes normal, or is improved by means of convergence to a nearer point, H. is said to be *relative*, in which simultaneous binocular vision is impossible, it being either monocular with a monolateral squint, or alternating binocular with an alternating squint. The relationship between H. and convergent strabismus is more fully dealt with under the latter subject.

Spasm of Ac. is the condition that results if a Hypermetrope exerts more Ac. for distance than the degree of H. If, in H. 3 D. the Ac. = 3 D. and none of it can be relaxed, the H. is said to be all latent; if 4 D. Ac. is exerted in the same defect, it is termed *spasm of Ac.* Accommodative spasm generally results from uncorrected As. and causes H. to be apparently M. The term *spasm* is sometimes applied in those cases which, although manifesting H. have a large percentage latent.

Acquired H.—Apart from H., which is due to an undeveloped condition of the eye, there is that known as *acquired H.*, which may result from (*a*) removal or dislocation of the crystalline lens—*i.e.*, aphakia (*q.v.*), (*b*) increase of the refractive index of the vitreous humour due to general disease, (*c*) decreased refractive power of the eye due to age. The term *acquired H.* is commonly and more definitely applied to this last condition. Acquired H. becomes noticeable at fifty or fifty-five years of age, when an eye previously Em. becomes H., or if previously H. the defect increases, while M. becomes less, and later may become Em. or even slightly H. The causes of acquired H. are not exactly proved, but it is thought to be due to increased density of the cortical layers of the crystalline lens. If this occurs, instead of the light being refracted at successive layers of the lens, which increase gradually both in density and curvature, it is refracted more at the outer but less at the central layers, so that the effect of the higher curvature of the nucleus of the lens is lost. To this may be added the effect of three other possible changes produced by age, viz., (*a*) lessened curvature of the front surface of the crystalline, (*b*) increased thickness of the crystalline lens, and (*c*) increased density of the vitreous. As a physiological condition (*c*) is not recognized; (*a*) and (*b*) are not definitely proved. Moreover, the influence of (*b*) would be small and doubtful as to causing H. Flattening of the cornea can also be excluded.

Whatsoever may be the causes, it is known that at a certain period of life the eye, as a refracting body, commences to lose some of its power, and the reduction continues year by year, showing *approximately* the following:

Age	55	60	65	70	75	80
Acquired H. in D.'s ..	·25	·50	1·00	1·50	2·00	2·50

If a certain amount of H. be determined in an old person, it is of no interest to know how much of it is original and how much is acquired, since both are included in the same test and correction.

The Measure of H.—The measure of the total H. is the power of that Cx. lens with which, when Ac. is at rest, V. reaches its highest acuity. But until quite late in life or when under the influence of a cycloplegic, Ac. is never at complete rest, and we can in ordinary vision only obtain the measure of the manifest part of the defect. The lens which measures the total H. is that whose focus coincides with the true P. R. That which measures the manifest H. has its focus coincident with the apparent P. R. which obtains when Ac., representing the latent H., is in force. Manifest H. is measured by the strongest +lens which does not cause vision to be worse than it is with any weaker lens. For instance, if V. = 6/4 and remains 6/4 with +1·5 D. but becomes slightly worse with +1·75 D., the measure of the manifest H. is 1·5 D. A truer measure of the manifest H. is obtained, as described later, by finding the strongest +lens accepted by each eye, when both are engaged in vision.

The measure of the latent H. is the difference between the strongest +lens accepted before the application of a drug, and the +lens which gives best vision when the eye is under its influence. The measure of the manifest facultative H. is the same as that of the manifest when V. is normal. The measure of the manifest facultative, when V. is subnormal, is the difference between the strongest and weakest +lenses with which the best possible V. is obtained. The measure of absolute H. is therefore the weakest +lens which gives best vision.

Suppose V. = 6/18, becomes 6/6 with +1·5 D., is still 6/6 with +3·5 D. and under atropine is 6/6 with +4·5 D; then the total H. is 4·5 D., the manifest 3·5 D., the latent 1 D., the facultative 3 D. and the absolute 1·5 D. In some cases a rough approximation of the total H. is the dioptric difference between the apparent and the assigned P. P. for that age. If the test is made with the +lens which corrects the manifest H., the same difference is very approximately the degree of latent H.

Effectivity of a Cx. Lens.—The greater the distance between a Cx. lens and the eye, the greater is the effectivity of the former. In under-corrected absolute H. if the lenses were put farther forward, they would improve V. because the light is then more convergent on entering the eyes; at the same time the retinal images become larger owing to advance of the nodal point.

Artificial Ac. is obtained by altering the distance of the lens from the eye; the subject is treated in another chapter. If equally clear vision results when a Cx. is moved outwards from the eye, it shows that most probably a stronger lens will be accepted.

The True Degree of H.—Since the effectivity of a Cx. lens increases as it is farther from the eye, it corrects more H. than is indicated by its number in diopters, although in low errors the difference is negligible. The true degree of H. would be represented by a thin auxiliary Cx. lens placed in the principal plane of the eye. If placed some 17 mm. in front of the latter, its focal length must be 17 mm. longer. Thus a true H. of, say, 5 D. would be corrected by a lens whose F. = 200 + 17 = 217 mm. or + 4·61 D.; that is, a + 4·61 D. placed 15 mm. from the cornea corrects 5 D. of true H. However, the method of indicating the degree of H. by the power of the correcting lens, as usually worn, is convenient and always understood unless otherwise stated.

Variations in the Degree of H.—Whatever the condition of a child's eye, the latter tends to develop with bodily growth, so that from childhood to maturity the total H. tends to decrease. During middle life it remains stationary until, at about 50 or 55 years of age, it commences to increase owing to *acquired* H. But while the total H. usually remains stationary between about 15 and 50, the manifest H. varies very considerably, increasing little by little every year with the diminution of Ac. In addition, the absolute manifest encroaches on the facultative manifest.

The P. R.—The far point is the conjugate focus of the retina when Ac. is totally at rest. In Em. it is at ∞, the retina being situated at F. of the dioptric system. In H. the retina is situated within F.; convergent light only can be brought to a focus at the retina, and, if light diverges from the latter, it emerges from the eye still divergent, although very much less so than before refraction; the point from which it apparently diverges on emergence is the virtual or negative P. R. of the eye. This is behind the principal point at a distance equal to the focal length of the correcting lens and, although the latter is placed at the anterior F. of the eye, instead of in the principal plane, it is sufficiently accurate for practical purposes. In all cases, no matter where the correcting lens is placed, its focal point coincides with the P. R. so that the latter may be defined as that point towards which light must be convergent, on entering the eye, in order to be brought to a focus at the retina by the static dioptric system. When H. is partly latent the apparent P. R. is more distant, or, expressed in diopters, it is less than the true P. R., which can be found only when the ciliary muscle is paralyzed by a cycloplegic.

The P. R. of a H. eye is similar to the virtual image of an object situated within the focal distance of a Cx. lens. The nearer the object is to F., the more distant is the image, while the nearer the object is to the lens the nearer also is the image. In high H. light emerges from the eye very divergently and, on being referred back, meets at a shorter distance behind the eye than in low H. where the P. R. is at a considerable distance. The P. R. is calculated by dividing 100 by the amount of H.—*i.e.* by the dioptric deficiency. Thus in H. ·5 D., 3 D. and 8 D. the P. R. is respectively at $100/-{\cdot}5=-200$ cm., $100/-3=-33$ cm., $100/-8=-12{\cdot}5$ cm.

If the defect is expressed by the correcting lens, the distance between it and the principal plane must be *added* to the estimated P. R. in order to obtain the true P. R. Thus, if a given case of H. be corrected by $+2$ D. placed 17 mm. in front of the principal plane, the true P. R. is at $100/-2=-50+1{\cdot}7=-48{\cdot}5$ cm. The P. R. in H. being negative, can only be determined indirectly by optometric measurement and is the apparent value only because Ac. is not totally relaxed. The P. R. is the most distant point of clear vision and in H. it is sometimes said to be beyond ∞; actually there can be no point of clear distant vision, this being blurred for all distances when Ac. is at rest. When fully corrected the P. R. is placed at ∞.

The P. P.—The P. P., or nearest point of distinct vision, obtains when all the Ac. is exerted. Since the hypermetrope exerts some Ac. for distance, he has less available for close work and therefore, with the same amplitude, his P. P. is more distant than in Em. Thus in Em. with an amplitude of 8 D., the P. P. is at $100/8=12{\cdot}5$ cm., while in H. 2 D. it is at $100/(8-2)=16{\cdot}5$ cm. The hypermetrope of 2 D. with 8 D. Amp. is in the same condition, in this respect, as an emmetrope with 6 D. Amp. If the H. is 5 D. and the Amp. also 5 D. the P. P. would be at ∞. Since the P. P. for the same Amp. is more distant in H. than in other refractive conditions, its measurement is of some utility in determining H. and estimating its approximate total or latent degree. A + lens which fully or partially corrects the H., places the P. P. nearer to the eye by a dioptric distance equal to the power of the lens.

Range and Amplitude of Ac.—Since some Ac. in H. is used for ∞, and the available amplitude for finite distances is thereby lessened, the range is restricted compared with Em. having the same amplitude. Thus in Em. with an Amp. of 10 D., the range is from ∞ to 10 cm.; in H. 2 D. with the same Amp., the range is from ∞ to 12·5 cm. In such a case the H. uses 2 D. Ac. to bring his P. R. to ∞, and has left only 8 D. Ac. available to represent his P. P. The full or partially correcting lens alters only the range, but not the Amp. Ac., by bringing both the far and near points nearer to the eye. More accurately stated the range, in the case illustrated, is from -50 cm. to 12·5 cm., but the negative portion is of no practical value, and although the available Amp. Ac. is lessened by H., the true Amp., of course, remains unchanged. Thus in the example given, the $\text{Amp.}=8-(-2)=10$ D., or the same as in Em. The sphincter fibres of the ciliary muscle are said to be more developed in low and medium H. and the actual Amp. Ac. at any given age is generally higher than in Em. and still more so than in M., but in some cases of absolute H. the Amp. Ac. seems to be considerably lessened.

Shortening of the Globe.—The axially H. eye is shorter than the Em. approximately ·33 mm. for each diopter of error; thus in H. 3 D. it is shortened 1 mm. Since the refracting power of the H. eye is presumed to be the same as in Em., the position of the nodal point, when the eye is at rest, is also the same, and we may consider that the shortening is totally behind the nodal point.

The Retinal Image.—Since the distance between the nodal point and the retina is shorter in H. than in Em. the retinal image is smaller. A comparison can, however, only be made when there is a sharp retinal focus in both cases. Cx. lenses increase the size of the retinal image by moving the nodal point forward, and this is the more pronounced as the lens is farther out from the eye. When the correcting Cx. lens is at the anterior focal plane of the eye, the retinal image is the same as it would be in Em. In axial H. with Ac. relaxed, the image formed (in theory) behind the retina is the same as in Em. A Cx. lens, placed at F_1, brings it forward to the retina without changing its size. Some other lens nearer than, or beyond, F_1, could also bring the image to the retina, but it would be smaller in the first case and larger in the second (vide *Retinal Image*).

Vision in H.—If Ac. is suspended parallel light tends to focus behind the retina and, therefore, at the latter circles of confusion are formed instead of point foci. These confusion circles overlap each other, so that vision is blurred, and is the more impaired as the circles are larger—*i.e.* the greater the degree of H. Divergent light from a near object causes still larger confusion circles since its conjugate is farther back, thus causing vision to be still more impaired. Only convergent light can be brought to a focus on the retina of a passive H. eye and as, in nature, light is either parallel or divergent, unaided vision, for all distances, is impaired with Ac. at rest. For clear vision the total refracting power of the eye must be increased by means of Ac. or a Cx. lens. In H. 3 D. the needed convergence to be given to parallel light would be obtained from a + 3 D. lens, or by increasing the ocular power by accommodating 3 D. The exertion of Ac. equal to the error is what usually occurs in H. of low degree and, consequently, vision is very good, and equal to or even better than, that found in Em. In high H. the needed Ac. action is usually impossible and therefore unaided V. is bad, especially for near objects.

If unaided V. is normal, it is the same with and without lenses and the latter cannot further improve it. If V. is subnormal, lenses must improve it and, although the V. A. is generally rendered normal, it is not as a rule so sharp as in the former class. Again, in many cases, the V. A. (*i.e.* corrected V.) remains lowered in high absolute H. because the eye, never having enjoyed clear vision, fails mentally to appreciate a sharp retinal image obtained by correction. Also, the H. eye, being underdeveloped, possesses fewer receptive and transmissive elements—*i.e.* rods, cones and nerve fibres, besides which the image is generally smaller than in the normal eye. It is always expected, in these cases, that the use of correcting lenses will improve the V. A. to some extent and this is often realized. When Ac. is active, there is no definite relationship between unaided V. and the degree of H. If Ac. be suspended, V. is approximately the same as in M. of a degree equal to that of the H., but the size of the pupil has some influence in this connection.

Symptoms and Troubles in H.—In absolute H., the vision is defective but not as a rule painful. Defective sight is accepted as a natural condition and vision for near objects, such as print, is obtained by holding the latter very near the eyes to secure large, although blurred, retinal images. The habit of reading close to the eyes may cause absolute H. to be mistaken for high myopia; in the latter condition, however, one eye only is generally employed, while in H. the use of both is usual. Facultative H. of low degree, in young people with normal acuity, rarely causes painful symptoms but sooner or later it must cause asthenopia and, at some period of life, the H. must become absolute.

Strain on the ciliary muscle causes frontal headaches. Restraint of excessive Con. by the external recti is manifested by neuralgic pain near the temples, especially with women. The necessity for Ac. in excess of Con. causes esophoria, or there may be a convergent squint.

Other symptoms are weakness, fatigue and dimness of vision in near work. The eyes and lids are apt to be red and inflamed; wind, dust and bright light cause annoyance, if not actual discomfort. The eyes feel tired, especially at night or on arising in the morning. There is a general feeling of ocular malaise and when, in near work, the eyes become tired, print, etc., is brought closer. The advent of wrinkles over the brows and near the temples is hastened by uncorrected H.

Asthenopia results because the demand on Ac. is excessive and constant. The emmetrope exerting equally Ac. and Con. can relieve any muscular strain in near work by looking at a distant object but the hypermetrope, needing Ac. in excess of Con., cannot obtain complete accommodative rest in this way. He must exert more Ac. at every distance than the Em., and the ciliary muscle is never in complete repose when the eyes are engaged in vision. But a still more potent cause of asthenopia lies in the fact that the effort of Ac. is greater than that of Con. When the efforts are equal, which is frequently the case, there is no asthenopia, notwithstanding that the resultant quantities of Ac. and Con. are not the same.

Thus asthenopia is more likely to occur when there is simultaneous binocular vision ; on the other hand it is less probable when vision is monocular, as when there is a squint. As a rule, asthenopia is more prevalent when vision is acute especially when much close work is done. If distant vision is painful in facultative H., near vision is still more so; frequently the complaints are only with respect to close work, but some suffer constant pain, strain, or headaches. Asthenopia continues until recourse is made to corrective lenses, or if this be not done it may disappear when, later in life, the H. becomes absolute and all excessive accommodative effort is abandoned.

While H. of low degree, in young people, permits of painless as well as good vision, this cannot continue throughout life. As age advances, and the accommodative power diminishes, the constant exertion of Ac. becomes more difficult, and asthenopia, not present in earlier life appears at, say, 25 or 30, but the advent of difficult and painful sight may be so late in life that it is often assigned to presbyopia rather than to H. itself.

The Determination of H.—If V. is normal and a weak convex lens blurs the sight, Em. is *apparently* indicated. If, however, vision remains the same as without the lens, it shows that the latter has replaced an equal quantity of Ac., previously exerted, and that manifest H. is present. If V. is subnormal a convex may improve the sight so that if any + lens improves *or does not impair vision*, whether normal or subnormal, H. is determined. In Em. or M., V. with a Cx. lens is worse than without it.

When there is simple H. As. (*q.v.*) there is occasionally some doubt as to whether a weak + lens does or does not blur V., and this doubt practically determines that condition. Even if a weak + sph. blurs the sight of each eye separately, a pair of such lenses applied simultaneously to the two eyes may not cause impairment of sight and, if this occurs, H. is determined. If H. is all latent, or if there is spasmodic Ac. action, a weak + sph. blurs V. ; the condition may, however, possibly be determined by the P. P.

So rarely is the Amp. of Ac. below that assigned to each age that it is quite safe to consider H. to be indicated if the P. P. is markedly beyond the position corresponding to the minimum amplitude, even though the weakest + sph. blurs the sight. Thus if at, say, 20 years of age, the P. P. shows only 8 D., it is safe to conclude that the eye is H. at least 2 D. It does not, however, follow that if the P. P. is at the minimum normal distance, or within it, the absence of H. is proved, because the amplitude is liable to vary considerably in different individuals of the same age. If H. is not determined by the foregoing methods, a cycloplegic may cause it to become manifest.

The following points should be particularly noted :

(*a*) *The fact that V. is normal does not preclude the existence of H.*

(*b*) *A + sph. does not necessarily improve V. when there is H.*

(*c*) *If a weak + sph. blurs V., the absence of H. is not positively proved,* *but merely that there is no manifest H.; there may be H. all latent or spasmodic Ac.*

(*d*) The fact that the P. P. shows more than the minimum Amp. of Ac. does not prove H. to be absent or that any other defect exists.

The Determination of the Degree.—H. having been determined, the power of the lens is increased until V. becomes worse and the lens immediately preceding that which commences to impair the sight, is the measure of the monocular manifest H. This lens, therefore, is the strongest with which V. is as good as, or better than, it is without any lens or with any weaker lens; if it is increased ·25 D. in strength it makes V. worse; if decreased ·25 D. it does not make V. better. A weaker lens allows more Ac. to be exerted, while a stronger one makes the eye practically myopic. Thus, if a person 20 years of age has manifest H. 2 D., he will probably see equally well through any + lens from ·25 D. to 2 D., but he will see less acutely through a +2·25 D. Then +2 D. is the measure of the manifest H., because a stronger lens impairs sight and a weaker one does not improve it. If, with the correcting lenses for the manifest H., the P. P. is farther away than the age warrants, the deficiency of power may be taken to lie in the static refraction. Thus suppose at 20 years of age +2 D. is accepted for the manifest H. and the P. P. is 8 D., then the deficient 2 D. represents latent H. although the amount would probably be greater than this. The deficiency in the Amp. may, however, be paretic or physiological.

The Binocular Test.—When the one eye is occluded binocular fixation is impossible and if, as is usually the case, there is a condition of esophoria, the one turns inwards behind the occluding disc while the other eye fixes. It is then found that Ac. does not relax so fully as when Con. is fixed for ∞. Hence it follows that the measure of the manifest H. is usually greater when binocular fixation occurs. After each eye has been corrected separately it may be found that equally clear vision is obtained when a pair of weak + sph.'s is added binocularly. The additional power, thus accepted, may be only + ·25 D., but it may be as high as +1 D. or even more, and it is usually greater as the hyperope is young and *vice versa.*

The measure of the manifest H., if the fullest correction is needed, as in high esophoria, is only obtained binocularly, but usually the correction of H. does not demand the binocular additional + power accepted. Also sometimes no H. at all is manifest except binocularly. On the other hand, when exophoria is present, the occluded eye may diverge and Ac. is less freely exerted, so that a high measure of manifest H. is obtained monocularly. When both eyes fix for ∞ the initial Con. then exerted is accompanied by Ac. action. In such a case, if normal V. be obtained monocularly, it may become blurred binocularly, or, anyhow, it is usually more difficult to repress the Ac. in binocular distant V. In order to clear the sight and produce harmonious action of Ac. and Con., it is necessary to reduce the power of the + lenses selected monocularly, and this is done by the addition of pairs of weak − sph. lenses. The power of the added − lenses, required for best vision, varies with the amount of initial Con. exerted; reducing the power of the + lenses allows more Ac. to be exerted but, as with binocular increase, a decrease of + power is not often needed.

Fogging Test.—A higher measure of H. is often obtained by over-correcting and then reducing the power of the + lens by means of weak concaves held in front of it. Thus, suppose with + 1 D. V. = 6/4·5 and with + 1·25 D. V. = <6/4·5, then with + 2 D., vision becomes considerably reduced. Adding − ·25 D. successively to the + 2 D., + 1·75 D., and so on, it may be found that finally V. = 6/4·5 with some + lens stronger than 1 D. To attain the highest + power that will be accepted, the fogging method should be employed binocularly. The power accepted by each eye is found separately and both lenses are increased by, say, 1 or 2 D. With these V. is blurred and *gradually* improved by holding pairs of weak − sph.'s in front of them, until the weakest Cc. lenses are found which, added to the + sph.'s, leaves V. as it was with the weaker + lenses obtained by the monocular test. This routine should not be done too rapidly but time given for the hyperope to attain relaxation of Ac.

Thus suppose the R. eye accepts + 2 D. and the L. + 3 D. and V. = 6/4.5. Increasing these to R. + 4 D. and L. + 5 D., V. = 6/36 approx. Placing a pair of − ·5 D. in front of the convex lenses V. improves to 6/24 and perhaps gradually to 6/18. Changing the lenses, by placing behind those in the frame, R. + 3·5 D. and + 4·5 D., and *then* removing the others, the process is repeated. Adding − ·5 D. V. will become 6/18 and perhaps 6/12. Again changing the + lenses and again reducing them ·25 D. and so on, it may be found that finally V. = 6/4·5 with R. + 2·5 and L. + 3·5 or with even stronger lenses than these.

The essential condition in the fogging test is that + lenses be not, at any time, taken from in front of the eyes; in this way the Ac. is not given any chance to become active. Any stronger + lenses must not be removed until the weaker lenses are in the trial frame. The same applies to the monocular test.

The Use of Fogging Lenses.—A very full correction of manifest H. causes part of the error to be alternately manifest and latent, as is shown by the variation in the visual acuity. If the strongest possible lenses accepted at any moment be worn, in the course of a few days V. becomes constantly clear. If lenses even slightly stronger than these, say ·25 D. or ·5 D., be given for constant use, the hyperope unconsciously relaxes Ac. to obtain clear vision, and the error is made manifest to that extent. By gradual continued increase by a quarter or half diopter of the power of the + lenses, a considerable amount of latent H. can be rendered manifest. This process is sometimes useful but in the majority of ordinary cases of H. the process of developing latent into manifest can be safely left to nature or time.

The Testing and Correcting of H.—The general rule is, that the corrective Cx. lenses are the *strongest* accepted or which do not cause vision to be worse than it is with any weaker lenses. These correct the manifest H. Total correction of the error is rarely given, except in special cases; such glasses simply cannot be worn and are discarded by those for whom they are prescribed. The correction of H. is that lens, for each eye, which causes light from ∞ to be focussed at the retina when the effort of Ac. is equal to that of Con. Consequently it follows that the essential consideration in correcting H., after equalizing the two eyes, is the balance between the internal and external recti, but the fact remains that, in the majority of cases, the correction is that lens, selected for each eye, which measures the manifest H. To this rule various exceptions and variations must be added. To avoid constant repetition, it is here presumed in what follows that (*a*) the age of presbyopia has not been reached, (*b*) that As. is not present, (*c*) that normal or practically normal V. is obtained, (*d*) that the eyes are healthy.

When V. is normal in each eye and there are no asthenopic conditions for any distance no glasses are needed. This resembles, and may be taken as, practically Em. If there is discomfort but distant V. is perfectly normal —*i.e.*, 6/4·5—and not improved by lenses, they need be used in *near work* only, even if there are complaints of the various inconveniences characteristic of the defect. Should, however, two or three weeks' use of the lenses not cause the asthenopia, headaches, etc., to disappear, then their use must be *constant.* It is always advisable to try the effect of the lenses in near work only, before recommending their constant use, since the latter will cause V. to become subnormal without lenses, whereas, previous to their use, it was normal. This occurs because, by using the lenses for distance, the eyes lose the ability to accommodate to a sufficient extent in excess of convergence. If lenses are given for constant wear, it is to be recommended that their use should be discarded for some hours daily in order to maintain the habit of distance Ac. Such hours for non-use of the lenses may, preferably, be when walking or when engaged in sports as rowing, tennis, golf, etc.

When unaided V. is subnormal as in absolute H. the lenses must be used constantly and it is expected that their use will cause improvement of sight if this be less than 6/6 when first corrected. When there is convergent strabismus—constant or periodic—or a tendency to squint, *i.e.* a high degree of esophoria, the use of the lenses should be constant. If there is low esophoria with a low or medium degree of H. it is better to commence with near work use only, and if there is exophoria it is still more advisable.

Further if lenses are centred for ∞, as is usual, they have an influence by acting as – prisms when the eyes converge, so that the Con. effort is increased and made still more in harmony with Ac.

Constant use of lenses tends to cause, with equal efforts, diminution of the excess of Ac. over Con.; in addition, as age advances less Ac. results from the same effort and H. becomes more manifest. The general rule for the correction of H. being the adaptation of those + lenses that represent the H. manifest, or made manifest, it follows that their power varies with age and becomes greater as the hypermetrope becomes older because the defect is then proportionately more manifest, although the actual total defect remains the same. As the hypermetrope grows older and has less Ac. he requires a larger proportion of his defect to be corrected artificially. A person H. 4 D. would, at 20 years of age, be satisfactorily treated with, say, + 2 D. lenses; at 30 or 36 he would need, say, + 3 D.; while at 40 or 45 he would require + 4 D. Still later in life, when acquired H. is also present, he would use still stronger lenses. They would be, say, + 4·5 D. at 60, + 5·5 D. at 70 and + 6·5 D. at 80.

On the other hand, as one gets older and has less available Ac. it becomes less necessary to give the full correction of the manifest H. Indeed with old people, if there is any choice, a weaker lens seems to be preferable, but for very old people or in aphakia where there is no Ac. at all there is no choice, since one power only will give a sharp retinal focus for a given distance.

Consequently, in considering the correction needed in H., the age is important. The Ac. becomes more difficult as age advances, so that we see many cases of H., which cause no inconvenience in youth or adolescence, become a source of trouble later on. Thus in H. of, say, 2 D., it may be quite easy to exert 2 D. Ac. constantly when the Amp. is 10 D., but it is no longer easy when the Amp. is reduced to 7 D. This is, indeed, what usually occurs in H. Whereas in youth the efforts of Ac. and Con. were practically equal, because the Ac. was easily produced, they are no longer equal when a greater Ac. effort is required in order to obtain clear vision. There are no rules as to the age at which H. causes discomfort, nor of the degree of error which does so, but a low amount of H. is more apt to trouble women than men and nervous more than phlegmatic people. The lens selected varies from the very strongest, to the one only which gives clearest distant V., as the hyperope passes from childhood to extreme old age.

When the measure of the manifest error is sought, it is usually found to be a variable quantity owing to fluctuation of the Ac. A convex lens causes suppression of Ac., but this again involuntarily comes into action, so that while V. is clear with a certain lens at one moment, it becomes blurred the next; or while V. is blurred by a certain lens, it presently clears up. It is not infrequently found that a difference of two or three lines of the test types will represent the varying visual acuity from moment to moment where Ac. is very active. Which of the various lenses giving best possible vision, at different moments, is the measure of the manifest error is a question difficult to state by rule. In young people a medium power, say the mean of the various lenses, may be selected and their use will cause the Ac. action to be more settled. Where there is a choice between two lenses give rather the weaker, as it is likely to be more comfortable than the stronger. If the muscular condition demands it, or the latent H. seems to be considerable, give the strongest accepted at any moment during the test. A full correction is best attained by gradual increase of the power of the lenses used. The very strongest accepted lens can be found only by the binocular test and by fogging (*q.v.*).

The use of drugs, in refraction work, is very much less general to-day than it was formerly, and this is due to improved knowledge of the refractive conditions of the eye and of their intimate connection with the muscular conditions. Nevertheless in young people, say those under 15, the proportion of latent H. is so great, that it may be advisable to learn the degree of the total error. It can be recommended that (*a*) non-medical refractionists should not correct these cases, (*b*) that medically qualified refractionists should measure them under cycloplegia, (*c*) that where an oculist is non-available, the optician should obtain the assistance of a medical man and, under his direction, refract such cases.

In older people, where there has been considerable strain on the eyes (due mainly to astigmatism perhaps), where all the H., or a large portion of it, appears to be latent, or where there is a squint, the eyes *may* need to be refracted under the influence of a drug. After atropine has been applied, the degree of manifest H. is generally larger than it was before, and this especially occurs if convex lenses be constantly used while the eyes are recovering from the effects of the installation. It does not, however, follow of necessity that lenses fitted under cycloplegia are better adapted for a given case than those which would have been selected without the drug; a correction of the original manifest H. only is required in most uncomplicated cases, but it might be impossible to cause acceptance of the needed lenses, owing to spasmodic Ac., without the use of a drug.

There is no evidence that the forced development of the normal latent into manifest H. is any advantage whatever, so that unless there are contra-indications, this should not be hastened by drugs or lenses. To some extent it must occur if lenses are used, but the action is greater if the correction is forced, *i.e.* made as high as possible, a procedure that, on general principles, should be avoided.

Glasses should prove comfortable when first fitted. At the same time it is often difficult to avoid causing some slight discomfort when glasses are first worn, no matter what care be taken in their selection. If the use of glasses which correct more than necessary of the total error be persisted in, discomfort caused by their use may disappear, but it is more rational to give comfort at the start and continue to do so by changing the lenses for stronger ones as age advances. There should be no period of transition from discomfort to comfort, because the former should be avoided if possible.

Esophoric and Exophoric H.—Esophoria, or a tendency to convergence, is the condition of the muscles usually found associated with H. For fusion at any distance, therefore, the Con. effort is small. In order that the Ac. effort may be brought into harmony it must be suppressed to a considerable extent, but if this be done to too great an extent there may be complaints that the lenses seem to "draw the eyes" or cause headache between the brows. Previous to their use there was strain on the ciliary muscle and on the external recti; discomfort resulted from the effort of Ac. being in excess of that of Con. With lenses these conditions may be reversed. The ciliary, accustomed to free action, is now called upon to repress itself, the internal recti are required to act in an unaccustomed manner to produce singleness of vision, and the effort of Con. exceeds that of Ac. Therefore, when esophoric the H. should be fully corrected so far as it is manifest.

Exophoria with H. is the exception. In this condition Con. is difficult and a greater effort has to be made in order to cause fusion of the images ; but it is more easily affected if associated with strong Ac. action. In exophoric H. the Ac. and Con. may be in harmony until fairly late in life when, the Amp. of Ac. being lessened, it is necessary to make a greater Ac. effort in order to see clearly. When exophoria is present a full correction of the H. is generally not tolerated in binocular vision ; the correction should be modified, it being, if not the weakest or nearly the weakest lenses that give good vision, at least one that undercorrects the manifest defect. The lenses required are those that measure the manifest error, reduced in power sufficiently to equalize the Ac. and Con. efforts. There are many exophoric hypermetropes who wear Cc. lenses with comfort. In orthophoria, if the correction could be expressed by rule, it would lie between those indicated for Eso. and Exo. In all cases the object aimed at is to harmonize the *efforts*, and not the *quantities* of Ac. and Con., the corrective lenses being of a strength that represent the deficient refraction when the Ac. and Con. efforts are equal. To briefly summarize the conditions, esophoria demands a full correction of the manifest H. ; orthophoria a nearly full, and exophoria a partial correction. The muscular condition is a most important factor and should invariably be considered when adapting the lenses.

Reasons for Correcting Lenses.—Lenses do not necessarily improve V. except in absolute H., but they enable close work to be carried on with greater comfort and prevent, or cure, asthenopia, heterophoria, strabismus, etc.

Distance and Close Work.—The lenses needed in H. are selected by the distance test and these, provided there is no presbyopia, also serve for near work. The apparent necessity before the presbyopic age, for different powers for distance and near work in ordinary cases, points to a faulty estimation of the error; an abnormally lessened accommodative action before 40, indicates rather the attention of the surgeon. Nevertheless exceptions to the above may perhaps be met with in exophoric cases where little or no + power is tolerated for distance, and especially at ages approaching that of presbyopia; also in cases of high H. where the *lessened* increased effectivity of the distance glasses, due to the divergence of the light, is an appreciable factor.

H. and Presbyopia.—When Ac. after 40 or 45 is insufficient for sustained close work, presbyopia is present and extra Cx. power is needed to aid near vision. Since Ac. is generally very active in low H., Pres. comes on rather later than in Em., although high absolute H. proves an exception to this rule.

Binocular and Monocular Fixation.—There is generally binocular simultaneous fixation in H. whether it is associated with Exo-, Eso- or Orthophoria. There may be, however, constant deviation of the one eye and consequently monocular vision, or alternating deviation of each eye with alternating binocular vision, or a periodic deviation of either eye with periodic monocular, and simultaneous binocular vision.

Convergent Strabismus.—If the harmony between Ac. and Con. be broken, the H. exerts more of the former than of the latter and secures clear vision without squinting. Thus in H. 2 D. provided that Ac. = 5 D. and Con. = 3 M. A. there is clear binocular V. at 33 Cm. If the harmony between Ac. and Con. be maintained, both being equally exerted, there is either clear V. of one eye accompanied by a convergent squint, or there is blurred binocular vision and no squint.

In H. 4 D., where Ac. = 4 D. accompanied by Con. = 4 M. A. the distance of Con. is 25 cm. while that of Ac. is at ∞. It is, therefore, impossible to see binocularly at ∞, and it is equally impossible to see clearly at 25 cm. since the Ac. is adjusted for ∞. If the Con. decides the resultant condition, the exertion of Con. = 0 is accompanied by Ac. = 0 and clear V. is impossible; the H. is absolute. If the Ac. decides it, there being 4 D. exerted, there is clear V. of one eye and convergent strabismus; the H. is relative. Convergent concomitant strabismus being caused by H., the essential for its cure is the use of Cx. lenses (*vide* Strabismus).

APHAKIA.

Derivation.—*α*, without; *φακος*, a lens.

Causes.—Absence of the crystalline lens may be, but is rarely, congenital, but the term is sometimes applied to the condition where there is dislocation of the crystalline which may be congenital, acquired spontaneously or traumatic, *i.e.* the result of a blow or wound. The usual cause of aphakia is extraction of the lens on account of cataract.

Symptoms.—The iris is tremulous because, the lens being absent, there is nothing to support it at the pupillary margin. If an iridectomy has been performed there is a gap in the iris extending from the pupil to the corneal margin, so that the pupillary area is enlarged and there is no response to light. This may cause photophobia and sometimes there is red or blue vision. Absence of the lens is demonstrated by the Sansom-Purkinje test wherein only the first or corneal image is seen, the two lenticular images being absent.

The Optical Condition.—When the crystalline, whose power *in situ* is approximately 16 D., is removed from an Em. eye, there is this deficiency in the refraction causing a high degree of H. The optical defect can be corrected by a suitable convex lens, whose power is less than 16 D., placed in front of the eye, but there is, of course, an entire absence of accommodation. A few cases are on record where the apparent phenomenon of Ac. in aphakia has been noticed in that, with the same lenses, the subject was able to see clearly at a distance and read ordinary type, but in these cases the pupil invariably resembled a vertical slit. With a pupil of this shape and looking obliquely downwards through a strong Cx. lens it would be possible for fairly small type to be read with the distance lenses.

The Retinal Image.—In the ordinary eye the size of the retinal image is governed by the distance between the nodal point and the retina, this distance being about 17 mm. This is very nearly the same as in the aphakic eye, so that if a clear retinal image were obtained from the refraction of the cornea it would be in aphakia much the same as in Em., both eyes being 24 mm. long. But if an eye of normal cornea and length be aphakic, the image tends to be formed considerably behind the retina, and a clear retinal image can only be obtained by the aid of a strong + sph. placed in front of the eye. The retinal image of the corrected aphakic eye is therefore considerably enlarged, although not so much as it would be if the lens were at F_1, which is 24 mm. in front of the cornea; the lens is generally only at 15 mm. and therefore well inside of F_1.

Visual Acuity.—Without lenses vision is naturally very reduced. With lenses it is lessened because there is usually some turbidity of the capsule of the lens and moreover the aphakic eye is more or less unhealthy or is old; consequently we find V. reduced in aphakia notwithstanding correction, but the diminution is lessened by the fact that the retinal image is larger than in the ordinary eye. Confusion also results from inability to contract the pupil as well as from its increased size owing to the iridectomy, but the effect of the iritic gap is not marked when the iridectomy is above and therefore covered by the upper lid.

Monocular Aphakia.—When the one eye only is aphakic and the other has good vision, it is often impossible for the two to be used simultaneously. In this case each eye should be provided with the necessary lens mounted in its own frame and both used for vision separately. Sometimes there is some reading distance for which simultaneous vision can be obtained with suitable lenses; if possible this should be found. When, however, confused binocular vision results, the one eye can be occluded by a ground glass or other means to prevent it seeing clearly while the other is in use. If the one eye is non-seeing, owing to cataract or other cause, it need not be considered and the distance lens can be mounted in the one eye-wire and the reading lens in the other, the frame being of a reversible type so that the one or other lens can be brought in front of the seeing eye. The confusion of vision if the one eye is non-aphakic and can accommodate, while the other is aphakic and cannot, when fusion by them is attempted, is chiefly due to the difference in size of the retinal images.

Operation Aphakia.—After the operation the surgeon generally does not permit the eyes to be used for clear vision for about three weeks, more or less. At first coloured glasses are used as the eyes are very sensitive to light, and some six weeks or two months are allowed to elapse before ordinary working lenses are adapted.

Astigmatism.—The necessary incision of the cornea generally produces a high degree of As. against the rule, which becomes less in the course of time and may entirely disappear. This acquired defect may increase or neutralize previous corneal As., while previous lenticular As., whether static or dynamic, disappears.

Dislocation of the Lens.—This condition requires surgical attention. The edge of the crystalline may bisect the pupil, in which case monocular diplopia results.

The Selection of the Lenses.—There is only one lens that gives best vision; this is the measure of the H. and the one required for distance. It is usually about + 11 D. placed some 15 mm. in front of the cornea for an eye which was Em. previous to the operation, while if previously H. or M., it is respectively stronger or weaker. The lenses, being very strong, should be centred for the distance at which they are to be chiefly used in order to avoid undue prismatic action, and for general use, as for walking, a lens which adjusts the eyes for, say, 2 m. or ·5 D. is often preferable as then the ground, etc., is more clearly seen.

There being no natural Ac. clear near vision can only be effected by lenses. For seeing at 1 m., 33 cm., etc., there is needed an additional power of respectively + 1 D., + 3 D., etc. The reading distance, on account of the reduced visual acuity, is generally short, say 33 cm., 25 cm., or even 20 cm., so that 3, 4 or 5 D. must be added to the distance glasses for reading purposes.

Artificial Ac. can be effected to a certain extent by moving the lenses to and fro in front of the eyes; it is the more easily achieved because, the lenses being very strong, the object viewed is always beyond 2 F., so that increased effectivity is obtained by advancement. The method of calculation is shown elsewhere. For reading purposes the glasses should be selected when placed not too near the eyes, so that objects situated rather nearer and farther than the usual distance can be seen by pushing the frame farther out and nearer respectively.

Calculation of the Correcting Lens in Aphakia.—When the crystalline is extracted the eye is reduced to an optical system of one refracting surface, viz., the cornea which, with the aqueous and vitreous, forms a uniform medium of $\mu = 1 \cdot 33$. Let L, the length of the eye, be 24 mm., $F_1 = 24$ mm. and $F_2 = 32$ mm. (Vide Chapter on *Ocular Calculations.*)

The formula for conjugate foci with a single surface is

$$\frac{F_1}{f_1} + \frac{F_2}{f_2} = 1$$

Calling f_1 the far point R, and f_2 the length of the globe L, we obtain the following which gives the P. R. and, therefore, the degree of H. caused by extraction of the crystalline from a previously Em. eye.

$$R = \frac{LF_1}{L - F_2} = \frac{24 \times 24}{24 - 32} = \frac{576}{-8} = -72 \text{ mm.}$$

The eye has a P. R. of 72 mm. behind the cornea or $1000/72 = 14$ D. H. and if the correcting lens be placed, as is usual, about 15 mm. in front of the cornea, its focal length would be $= +72 + 15 = +87$ mm. or $+11 \cdot 5$ D.

Em. in Aphakia.—In order that an eye be Em. after extraction of the crystalline it must be 32 mm. long or myopic about 20 D., so that the retina may be at the focal distance of the cornea.

Previous Am.—From the above formula there can be found the P. R. or the focal length of the correcting lens *at the cornea* for any length of globe and to this should be added 15 mm. to obtain the focal length of the correcting lens at the usual distance, treating, of course, the negative P. R. found as a positive quantity when adding the 15 mm. Or if the P. R. measured from the cornea be known, the length of the globe L can be found from

$$L = \frac{32\ R}{R - 24}$$

From the formula $Rb = F_1F_2$, we can obtain R the far point, measured from the anterior focal point, or b the distance of the retina from the posterior focal point. Now in aphakia $F_1 = 24$ mm. and $F_2 = 32$ mm. from the cornea, whence $Rb = F_1F_2 = 24 \times 32 = 768$ and $b = L - 32$, so that

$$R = \frac{768}{L - 32}$$

and the correcting lens placed at F_1 in terms of the axial length L in mm. is

$$D = \frac{32000 - 1000\ L}{768} = 41 \cdot 67 - 1 \cdot 3\ L$$

Thus if $L=24$ mm. the value of D in the anterior focal plane is 10·47 so that if the lens is placed 15 mm. from the cornea, or 9 mm. behind F_1,

$$D=\frac{41{\cdot}67-1{\cdot}3\,L}{1-{\cdot}009\,(41{\cdot}67-1{\cdot}3\,L)}=11{\cdot}5$$

as before calculated.

In ordinary Am. where D' is the correcting lens 15 mm. in front of the cornea

$$b=L-24=-{\cdot}37\,D' \text{ or } L=24-{\cdot}37\,D'$$

Then by substituting the value of L in terms of D' we get

$$D=\frac{41{\cdot}67-1{\cdot}3\,(24-{\cdot}37\,D')}{1-{\cdot}009\,[41{\cdot}67-1{\cdot}3\,(24-{\cdot}37\,D')]}$$

which works down to $D=\dfrac{11{\cdot}5+{\cdot}531\,D}{1-{\cdot}0048\,D'}$

From this we find that an original myopia of 22 D. would result in an aphakic emmetropia.

An operation involving the cornea usually affects its general refracting power as well as causing As. Also if the normal globe were 25 mm. in length or if the cornea had a radius of, say, 7·5 mm., the correcting lens in aphakia for an eye originally Em. would be weaker than +11·5 D. and is usually said to be +10 D. In the following table this latter is taken as the basis for the figures given in (2), while those of (3) are on the basis that the normal eye is 24 mm. long, and that operation has not affected the curvature of the cornea, the radius of which is 8 mm. (1) gives the original defect expressed in terms of the correcting lens placed 15 mm. in front of the cornea.

TABLE OF CORRECTING LENSES.

1	H. 10 D.	H. 8 D.	H. 6 D.	H. 4 D.	H. 2 D.	H. 1 D.	Em.	M. 1 D.	M. 2 D	M. 4 D.	M. 6 D.	M. 8 D.	M. 10 D.	M. 12 D.	M. 14 D.	M. 16 D.	M. 18 D.	M. 20 D.	M. 22 D.
2	+15·75	+14·5	+13·5	+12·25	+11	+10·5	+10	+9·5	+9	+7·75	+6·5	+5·5	+4·25	+3	+2	+1	0	−1·5	−2·25
3	+17·75	+16·25	+15	+13·75	+12·5	+12	+11·5	+11	+10·5	+9·25	+8	+7	+6	+4·75	+3·75	+2·75	+1·75	+·75	0

An approximate calculation, which is curiously correct, as can be seen from the above table, is to add half the original correcting lens to +11·5 D. or to +10 D.

Variation of b.—Since $Rb = 768$ or $R = 768/b$ we have the power of the correcting lens, expressed in terms of the distance between the retina and F_2, as

$$D = \frac{-1000b}{768} = -1{\cdot}3b$$

but here the lens is 24 mm. in front of the cornea. If placed at 15 mm. it would need to be stronger, and the power of the correcting convex lens in aphakia for each mm. the eye is shorter than 32 mm. varies, not by a fixed quantity, but by one which increases as the eye is shorter. For long eyes each mm. represents 1·3 D. (approx.); if the eye be about normal length, each mm. = 1·44 D. (approx.) and in very short eyes each mm. = 1·55 D. (approx.). A rough calculation is, say, 1·5 D. for each mm. the eye is shorter than 32 mm. If the eye were so long as to still need in aphakia a concave lens the latter varies by about 1·2 D. for every mm. increase of length beyond 32 mm.

CHAPTER VI

MYOPIA

Derivation.—μυω, close; ωψ, eye.

Definitions.—Myopia (Fig. 49) is the condition of an eye in which, when the Ac. is suspended, parallel light comes to a focus in front of the retina, the latter being situated beyond the principal focal distance of the refracting system. It therefore follows that in M., the P. R., or conjugate focus of the retina, is positive and situated at a finite, or measurable distance, in front of the eye, as in Fig. 50.

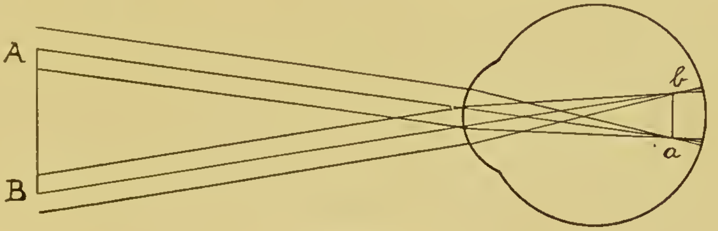


Fig. 49.

M. is illustrated by a screen placed slightly beyond F. of a Cx. lens. Parallel light, after refraction, focusses before reaching the screen; light diverging from the latter emerges from the lens convergent to a point in front of it.

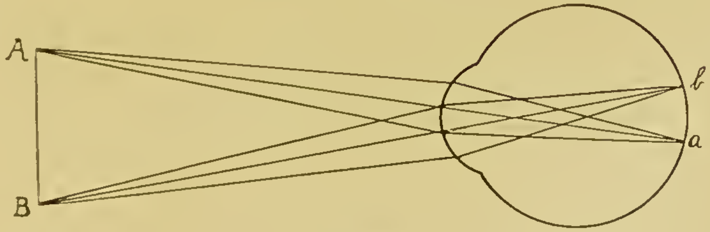


Fig. 50.

Causes.—The condition may be the result of too great an axial length while the refracting power is normal; or, alternatively, the globe may be of normal length but the refracting power too great. The former is termed *axial*, and the latter *refractive* M. The result is the same in both, since the focal length is less than the distance from the principal point to the retina. The condition of M. obtains because the refractive power is excessive for the length of the eye, and not because the eye is too long *or* because it has too much refracting power.

Age of Appearance.—It is rare that M. develops before the ages of 8 or after 20. Usually it becomes apparent between 10 and 16, at that period of school life when not only is growth rapid and continuous, but the eyes are also largely employed in close work. This is the danger age for children's eyes, during which they should be kept under observation. M. is not likely to have become acquired before 10 because, up to that age, axial development would not exceed the normal, but result merely in diminished H. or the attainment of Em. After maturity the eye, having reached its full development, is unlikely to acquire a tendency to abnormal growth. The malignant form may commence much earlier.

Prevalence.—It is said that M. is a product of education and civilization; certainly it is more prevalent in cities than in towns, in towns than in rural districts. It is possible that vision, being restricted by the surroundings, tends to produce a short-sighted class, and, in general, the inhabitants of large cities and towns are more inclined to sedentary occupations, and enjoy less light and air, than country-people. M. prevails more in one country, compared with another, as the educational attainments are greater; among savages it is practically unknown, and it is rare among races of little or no education. The percentage of myopes increases in schools in a direct ratio with the class or standard, so that while the percentage is almost *nil* in a primary village school, it reaches a considerable figure in an advanced urban educational establishment.

Apart from all other reasons, there is a higher percentage of myopes, and a higher average defect, in those countries where knowledge of refraction work is limited and these become lower as the science of optics becomes more general and exact, notwithstanding that education becomes more universal and of a higher order. This is, also, in part due to the greater care exercised in the lighting, ventilating and fitting up of schools as well as to the systematic testing and correction of children's sight. Nevertheless, in this connection, while the principles adopted, when they *are* adopted, are in themselves good, their application leaves, in many cases, much to be desired.

M. Congenital and Acquired.—M. is the result of axial development of the eye, with respect to the focal power, beyond that which would cause it to be Em. M. therefore is essentially an *acquired* condition; it is also very frequently hereditary, the children of myopic parents being born with the tendency to acquire the defect. One form of M., acquired late in life, is due to changes in the crystalline and is termed second sight (*q.v.*). It is said that no child is born M., yet this seems to be possible and certainly eyes are sometimes found to be so exceedingly M. at so early an age, that probably some of it, at least, was present at birth.

Refractive M. may be due to a relatively high curvature of the cornea or crystalline and is then termed *curvature* M. It could be caused also by (*a*) a high refractive index of the cornea and aqueous, (*b*) a low index of the cortical layers of the lens, (*c*) a high index of the nuclear portion of the lens, (*d*) a low index of the vitreous. Appreciable variation in the indices of refraction of the media and curvature of the surfaces of a *healthy* eye can be excluded and, with reference to the cornea, a lessened rather than an increased curvature is more probable in high M.

Axial M.—Undue length of the globe is the ordinary and usual cause of M. The refractive power and focal lengths are presumed to be the same as in Em., but the retina is situated beyond the posterior focal plane.

Degrees of M. vary from a small fraction of a diopter to, say, 20 D. or even more, for cases of 30 D. or 40 D. have been recorded. M. not exceeding 1 D. is considered *very low;* up to 3 D is *low;* between 3 D. and and 6 D. is *medium;* from 6 D. to 10 D. is *high;* over 10 D. is *very high.*

The Optical Condition.—Although M. is due to excessive length of the eye yet, as an optical error, it is more conveniently regarded as a condition of excessive refracting power. If the Em. refraction is 50 D., it may be considered that in M. the refracting power is greater than this; thus in M. 3 D. the refraction is 53 D. and the excess 3 D. could be neutralized by a – 3 D. lens. The condition of M. is positive, and the correction of the optical error is a negative or – lens, the power of the latter expressing also the degree of defect. It can be produced artificially by placing a Cx. lens in front of an Em. eye, or an over-correcting lens in front of a H. eye.

Ac. in M.—For all distances the M. eye exerts *less* than does the Em., as many D.'s of Ac. as there are D.'s of M. Thus in Em. for 40 cm. Ac. = 2·5 D. so that in M. 1 D. there would be exerted only 1·5 D.; in M. 2 D. only ·5 D., and in M. 2·5 D., Ac. = 0 for seeing clearly at this distance. If the degree of M. exceeds the amount of Ac. required by the emmetrope at a given distance, clear vision for the myope, at that distance, is impossible; in other words, the myope cannot see distinctly beyond his far point, at which he sees distinctly without using any Ac. When the M. is fully corrected the exertion of Ac. is the same as in Em., and when partially corrected the Ac. exertion is less than it is in Em., to an extent equal to the amount of M. left uncorrected. Thus in M. 3 D. with a – 2 D. lens, the Ac. action is the same as in M. 1 D.

Con. in M., expressed in M.A.'s, is the same as in Em.

Ac. and Con.—Con. in excess of Ac. always occurs in M., when uncorrected or partially corrected. For example in M. 3 D., for reading at 33 cm., Ac. = 0 while Con. = 3 M. A. Similarly at any nearer distance the excess exertion of Con. is 3 units of that function. If the M. were partially corrected by a – 1 D. lens, Ac. = 1 D. at 33 cm. and Con. exceeds Ac. by 2 units for that and all other distances at which clear vision is possible. When the M. is fully corrected Ac. and Con. are equal in quantity.

Divisions.—There is no classification of M. as there is of H., but it may conveniently be divided into two classes which, for want of better names, may be termed *healthy* and *dangerous.*

Healthy M. includes all cases where, with corrective lenses, the visual acuity can be raised to the normal and other conditions, as in the following paragraph, do not apply. A case of M. which would be regarded as a perfectly healthy condition in a person of mature age, becomes a doubtful, or even dangerous case in a child or youth who is still growing. The essential point about this class is that optical treatment alone is needed.

Dangerous M. includes cases where the visual acuity is subnormal after correction and cases of *true progressive M.* These require, or may require, more than mere optical correction. In addition, M. in children under 15 years of age and cases of high degree, although the eyes may be perfectly healthy, should be included under this heading, because they may become serious conditions if not treated from a hygienic as well as from an optical aspect.

Progressive and Stationary M.—Although all cases of M. have necessarily been *progressive,* the term is specially applied to those which continue to increase notwithstanding proper optical treatment, and to those where the increase is abnormally rapid or takes place after maturity. M. is *stationary* when it remains a fixed quantity for some years at least. M. is more likely to increase, after correction, in young than in older people and if removal of the causes does not prevent further development, the case must be considered *dangerous.*

Uncorrected M. generally becomes stationary at maturity, but even then may suddenly become progressive after illness, etc., especially if no glasses are used or if those used are too strong. Some cases have periods, during life, of alternate progression and quiescence. As a rule, after 20 years of age, M. may be considered stationary and if it does not then exceed, say, 4 or 5 D., it is very unlikely that it will ever become progressive. It is difficult to draw any definite line between progressive or dangerous, and stationary or healthy M. The essential points are (*a*) that what is healthy in an older eye, may need to be regarded as *dangerous,* or likely to be dangerous, in a young eye and (*b*) that optical maltreatment may, at any age, turn a healthy condition of M. into a dangerous one. True malignant M. (*q.v.*) is always more or less progressive.

Malignant M. is the name given to those cases which have been produced by close work during school life, and attain to a very high degree. Here the malignant character may be the result of maltreatment, or non-treatment, of an optical error in an originally quite healthy eye. The term is perhaps more properly applied to those cases which, if not actually present at birth, develop very shortly afterwards and continue to progress during life. It is a congenitally morbid condition and a form of choroiditis in which extreme elongation of the globe is a symptom. It is just as likely to be found in one who cannot read or write and who has never used his eyes for continued close work, as it is in the most ardent student. In fact it is more often encountered among the poorer and less educated classes, than among the wealthier and better educated. Malignant M. may terminate in partial or complete blindness.

Spasm of Ac.—Since Ac. for distance can only have the effect of further reducing the visual acuity in M., it must be regarded as true spasm if it is exerted; excessive Ac. may also be exerted for near work and the cause is, nearly always, uncorrected As. The general result is an apparent degree of myopia in excess of the true amount of error.

Accommodative M. is the name sometimes given to the condition which exists when a H. or an Em. eye appears to be M. owing to spasm of Ac.

Second Sight is a form of acquired M. caused by senile cataract. It is due to changes in the crystalline lens whereby its total refractivity is increased.

The Measure of M. in any case, is the power of the *weakest* concave lens with which V. is made as acute as possible, the Ac. being at rest. Otherwise expressed it is the power of the lens whose focus coincides with the P. R. of the eye.

Effectivity of a Cc. Lens.—The more remote a Cc. lens is from the eye, the smaller is its effect. Consequently if lenses undercorrect, the myope pushes them close up to the eyes in order to increase their effect and to enable him to see distant objects more clearly; the light is thus rendered divergent, as if coming from a point nearer to the eyes than if the lenses were farther out. At the same time the retinal image is enlarged by advancement of the nodal point. By moving the lens outwards artificial Ac. (*q.v.*) is effected. If a myope can see distant objects through a given Cc. lens equally well, when it is more remote, as when it is close to the eye, it shows that a weaker one is required.

The True Degree of M.—We speak of M. 1 D., 5 D., etc., according as the defect is corrected respectively by a -1 D. or -5 D. lens placed about 15 mm. in advance of the cornea, in the anterior focal plane of the eye, but as a Cc. lens decreases in effectivity as it is farther from the eye, it corrects less M. than its dioptral power indicates. The true degree of M. would be represented by a thin auxiliary Cc. lens placed in the principal plane of the eye. Consequently if placed 17 mm. in advance of this plane, the focal length must be 17 mm. shorter. Thus to correct true M. of, say, 5 D. we need a lens of $F. = 200 - 17 = 183$ mm. or approximately $-5{\cdot}5$ D.; in other words, a – 5·5 D. corrects only 5 D. of true M. It is, however, usual and convenient to indicate the degree of M. by the power of the correcting lens placed in the usual position.

Variations in the Degree of M.—The axial development of a child's eye to that of Em. or low H. is quite normal and is regarded as an abnormality only when it is so excessive as to produce myopia. Evidently every case must commence with a degree represented by a minute fraction of a diopter, which amount gradually increases until it becomes sufficiently high to cause a marked diminution in V. Therefore its degree is essentially variable up to maturity when both bodily and ocular growth cease. Others again show no increase after correction by lenses, since these remove the cause for its development. No diminution in M. can naturally occur except from acquired H. late in life. Thus ordinary M. increases in youth, remains stationary in middle life and decreases in old age. In general, therefore, it is contrary to the condition of H.

The P. R.—When Ac. is at rest, the far point is the conjugate focus of the retina and, since the latter is in M. beyond the posterior principal focus, only divergent light can be brought to a focus at the retina. If light diverges from the latter it is, on emerging from the eye, convergent to a certain point, the P. R., in front of it. Like the defect itself the P. R. is *positive* and its distance is governed by the degree of M., with which it varies inversely. If the P. R. is expressed in dioptric measurement it varies directly with, and is the same as, the degree of error. The far point is commonly taken to be equal to the focal length of the correcting lens but, while this is sufficiently exact for practical purposes, it is not accurate since the correcting lens is some distance out from the refracting plane. In all cases, the focal point of the correcting lens, wherever placed, coincides with the P. R. so that the latter in M. can be defined as that point from which light must diverge in order to be brought to a focus at the retina without Ac. The correcting concave lens causes parallel light to diverge as if it came from the P. R.

The far point of a M. eye is similar to the real conjugate focus of an object placed beyond F. of a Cx. lens. The nearer the object to F., the more distant is the image and *vice versa*. Therefore in high M. the light emerges extremely convergent from the eye to meet at a short distance, while in low errors the far point is comparatively distant. It is calculated in cm. by dividing 100 by the degree of M. or dioptric excess. Thus in M. ·5 D., M. 3 D. and M. 10 D., the P. R. is respectively at $100/\cdot5 = 200$ cm., $100/3 = 33$ cm., $100/10 = 10$ cm.

The true P. R. is obtained by *adding* to the estimated P. R. the distance between the principal plane and the lens. Thus if the correcting lens is – 5·5 D. placed 17 mm. in front of the principal plane, the true P. R. is at $100/5\cdot5 = 18 + 1\cdot7 = 20$ cm. approximately.

The farthest point of vision expressed in D.'s indicates the degree of M., but this test is uncertain because owing to the largeness of the retinal image the myope can often distinguish type beyond his P. R. On the other hand accommodative action or reduced V. may make the P. R. appear nearer than is actually the case, while As. may cause the distance to be indefinite. Nevertheless, for an approximate measurement, the test is useful. The P. R. being the most distant point of distinct vision, and at a comparatively short distance in M., vision for anything beyond it must be blurred. The fully correcting lens places the P. R. at ∞, while one which partially corrects the M. removes it by as many D.'s as there is power in the lens. Thus in M. 6 D. with a – 4 D. lens, the P. R. is the same as in M. 2 D. without a lens, namely, at 2 D. or 50 cm.

The P. P.—With the same Amp. as in Em. the P. P. is nearer to an extent equal to the D.'s of M. Thus if the Amp. of Ac. be 6 D., the P. P. in Em. is at 16·5 cm. while in M. 2 D., it is at 8 D. or 12·5 cm.; in M. 5 D. for the same Amp. it is at 11 D. When M. is corrected, the P. P. ought to be as near as it would be in Em. at the same age, but this cannot occur if the Amp. is reduced, which is so often the case. In no circumstances can the position of the P. P. determine M.; if it is nearer than the minimum position, assigned to any given age, it is probably because the Amp. of Ac. is greater than this minimum. The position of the P. P. may, however, serve to confirm a determination of M. made otherwise; without lenses the P. P. should be nearer than in Em. at the same age.

Range and Amplitude of Ac.—For the same Amp. of Ac. the range is lessened in M. For example, in Em. with an Amp. of 6 D., the range is from ∞ to 16·5 cm.; in M. 2 D. the range would be from 50 cm. to 12·5 cm. The P. P. is 4 cm. nearer, while the P. R. is brought from ∞ to 50 cm. When M. is fully corrected, the range is normal if the Amp. is normal; if the latter is reduced the range is so also. In low degrees of M. the Amp. of Ac. is practically the same as in Em. but in the higher degree it is, owing to non-use of Ac., often considerably lessened in proportion to the degree of defect, so that it is not unusual to find in high M. very little accommodative power, and a young myope of high degree may be in the same condition as a very old person in this respect. The constant use of corrective lenses have, however, the effect of maintaining, and often of restoring, good accommodative action if it has become depleted owing to non-use.

Lengthening of the Globe.—The increased length of the globe is about ·33 mm. for each D. of M.; thus in M. 3 D. the increase is 1 mm. We take it that the refractive power, focal lengths, and cardinal points of the myopic eye are the same as in Em. so that the increase of length may be considered to be entirely behind the nodal point.

The Retinal Image is larger in M. than in other conditions, because the distance between the nodal point and the retina is greater, but a comparison is only possible when the retinal image is sharp. Thus if an eye M. 3 D., and an Em. eye accommodated 3 D., observe an object at 33 cm. the retinal image is larger in the former. If the defect is purely axial, the image of a distant object formed in the vitreous of a M. eye is the same size as in Em. When the correcting lens is in the anterior focal plane the image is carried back to the retina but unaltered in size. A stronger lens beyond, or a weaker one nearer than, F_1 could also cause the image to be at the retina, but in the former case it would be smaller and, in the latter, larger than in Em. A full discussion on this point will be found in Chapter XX.

Vision in M.—Since parallel light is brought to a focus in the vitreous of a myopic eye, overlapping circles of confusion are formed at the retina and, consequently, *unaided V. is always subnormal*; the diminution is directly proportional to the size of the confusion discs and therefore to the degree of M. since these are larger as the focal plane is farther in front of the retina. Divergent light only can be brought to a focus at the latter so that, although unaided V. is defective for ∞, it may be very good for short distances, indeed near vision is usually better in uncorrected M. than it is in H. or Em. In high degrees, however, V. may be lowered for all distances by fundus degeneration and stretching of the globe, the latter also causing a given sized image to cover few retinal elements. In corrected low M. the V. A. is usually very good, but in high degrees it may remain subnormal for the reasons just mentioned; nor can it be improved by continued use of lenses beyond what results at once from a sharp retinal image. Usually Cc. lenses do not improve V. within the P. R.

Since V. cannot be normal in uncorrected M. and since Ac. is not employed for distance, it is possible to estimate from the degree of V. the approximate degree of defect if low. When V. is below 6/60 the M. exceeds 3 D., and a judgment cannot be then easily made. When V. is 6/60 or better the M. does not exceed 3 D., and approximately the two are then related as follows:

M.	..	2·5 D.	2 D.	1·5 D.	1 D.	·75 D.	·50 D.	·25 D.
V.	..	6/60	6/36	6/24	6/18	6/12	6/9	6/6

Here of course, and in fact throughout the whole of this chapter, As. is presumed to be absent; in the above, corrected V. is taken to be 6/4·5. In some cases the degree of vision is less, for a given amount of error, than that in the table, *but is very rarely more*, and if there are exceptions to this, it is safer for the student to believe that there are not. When M. = 3D. or less, or exceeds 3 D. but being partially corrected V. = 6/60, *vision should improve one line of the types for every additional* 1/2 *or* 1/4 *D. increase of Cc. power.* This has a very important bearing on the detection of spasm of Ac. as, in the latter, a far greater concave power than would be called for in true M. is required to raise vision from a certain point to the normal. The pupils are generally large in M. and V. is thereby decreased, but in old age they become smaller and tend to improve the sight by reducing the size of the retinal circles of confusion.

Symptoms and Troubles in M.—In low M., up to, say, 2 or 3 D., there may be any of the symptoms which accompany the higher degrees but, usually, the only complaint is that of inability to see distant objects, such as names of streets, the time from a public clock, or to recognize the features of friends, and a school child cannot see what is written on the blackboard. Although the myope of low degree complains of his defective distant sight he rather prides himself on his excellent near vision and ability to read continuously without fatigue. Some few suffer from asthenopia but the large majority of myopes of low degree do not. Some notice their defective distant vision very much but others are almost unaware of it.

In medium M., say, from 3 to 6 D. defective distant sight is more pronounced and other conditions tend to resemble those of higher M. where we find asthenopia owing to the exertion of Con. in excess of Ac., and to the high degree of Con. required; also headaches chiefly between the brows. Prominence of the eyes, which move slowly and with difficulty, as the long myopic globe cannot freely rotate in its cylindrical orbit. This is why the myope turns his head, rather than his eyes, even more than does the emmetrope or hypermetrope, and for the same reason Con. is the more sluggish, difficult and painful. Exophoria, due to functional inefficiency of the internal recti, is the usual muscular condition in M. Divergent strabismus is caused by inability of the internal recti to maintain fusion, and occasional diplopia may result from periodic strabismus; constant diplopia does not often result from squint caused by M.

The myopic crescent, which is a ring or crescent-shaped area of sclerotic at the side of the optic disc, having its Cx. edge towards the macula, is commonly seen in all myopic eyes and, unless more than usually developed, is not of importance. Should, however, the crescent be highly exaggerated, it denotes a serious condition (vide *Posterior Staphyloma*).

Low or medium degrees of M. may be apparently increased owing to spasm of Ac. the latter being probably caused by As. There may be photophobia, or intolerance of light, accompanied by the habit of half closing the eyes; lowering of the brows with consequent frowning is, for the same reason, sometimes noticeable. The habitual partial closure of the lids by some myopes acts as a horizontal stenopæic slit in improving vision; objects unrecognized with open eyes may be so when the latter are half closed, and the habit is more common when there is As. according to the rule (*q.v.*). Symptoms of the higher degrees of M. are: Print must be held very near in order to be read, and writing can only be managed by placing the eyes a few inches from it. So close indeed has such work to be done, that convergence and binocular fixation become impossible and one eye only may be used. Aching and pain at the back of the eyes, apparent flashes of light, redness and congestion of the lids and conjunctivæ, dancing print and *muscæ volitantes.* Reduced visual acuity may obtain notwithstanding the best optical correction. V. may reach 6/6 or only 6/9, 6/12, 6/18 or even less. A small reduction may be due to mere stretching of the retinal elements, the eye being perfectly *healthy*, but a greater reduction is generally due to changes at the fundus.

In addition, malignant M. may show a highly developed myopic crescent with a *posterior staphyloma, i.e.*, a bulging backwards of the sclerotic at the optic disc; scotomata or blind areas in the visual field; atrophy, hæmorrhage and pigmentation of the choroid, liquidity of the vitreous with opacities, or cells of altered refractive index, giving rise to *muscæ volitantes*; spontaneous retinal detachment may occur, or as a result of the fall or blow, and cataract may supervene as a further complication.

Asthenopia occurs partly on account of the high Con. effort required for binocular fixation, but still more because the effort of Con. exceeds that of Ac. If, as so often occurs, there is no asthenopia, it is because the efforts are equal although the quantities exerted are not, and indeed cannot be in uncorrected M.

Photophobia.—Intolerance of light is one of the concomitants of high M. or where there is asthenopia, but as a rule it disappears when the error is effectively corrected. If, however, it continues or if very pronounced tinted lenses may be required. Nos. 1 or 2 smoke or blue serve the purpose; deep shades tend rather to render the retina still more sensitive to light, or, at least, tend to maintain the extreme sensibility; for the same reason, their temporary rather than their continued use, is advisable.

The Determination of M. is made if with other corroborative details, a Cc. lens *definitely* improves V., which was subnormal without the lens, so that by its aid, smaller objects such as test types can be clearly distinguished.

When V. is 6/60 or better, a weak Cc. lens, say, ·5 or 1 D. should improve the sight one or two lines; there cannot be needed anything stronger than, say, −1 D. in order to determine the presence of M. and if such power does not improve the sight to some extent, M. cannot well be present. When V. is less than 6/60 a weak lens can only cause a very indefinite improvement, or none at all if the error is high. In these cases medium power lenses must be tried and the power rapidly raised until No. 60 type can be read. Or a rough approximation of the degree of error may be obtained from measuring the P. R. and a lens somewhat weaker than the measure thus obtained is then employed for the determination of M. For instance if the M. = 10 D. nothing weaker than – 7 D. would improve V. to 6/60 and until this occurs it cannot be stated that M. is determined. Therefore it may be said that, when V. is less than 6/60, M. is determined when it is raised to 6/60.

A definite improvement in sight is indicated by the ability to read, with the lens, test types which were indistinguishable without it. This, *and not merely sharper sight*, is needed before it can be said that M. is determined because frequently a weak Cc. lens apparently sharpens the visual faculty in Em. or H. Further, spasm of Ac. (*q.v.*) may cause false M. to be mistaken for the true defect but the latter is confirmed if fine print can be easily read near to the eyes, *i.e.* at or within the P. R.

It should be noted particularly that—

(*a*) *If V. is normal,* i.e. *if the maximum acuity for that particular eye is attained without any lens, M. cannot be present.*

(*b*) *If M. is present a Cc. sph. must definitely improve V.*, i.e. *give additional power to read distant types.*

(*c*) *A – sph. may slightly improve V., although M. does not exist* (*As. or spasm of Ac.*).

(*d*) The fact that the P. P. apparently indicates more than the *minimum* Amp. of Ac. for the age, *does not show that M. is present.*

The Determination of the Degree.—When M. is determined, *i.e.* V. raised to 6/60 or better the Cc. should be increased very gradually until the highest possible V. A. is reached. Thus if with any lens V. is raised to, say, 6/4·5, the measure of the M. is the power of the *weakest* Cc. lens with which this is obtained. If the lens is made a quarter diopter *weaker*, V. may be reduced, while if it is *increased* in strength the visual acuity *does not become higher* than 6/4·5. If V. cannot be improved beyond 6/9 or any other fraction, the degree of M. is represented by the weakest lens with which this fraction is attained. When a lens *higher* than the actual defect is placed in front of the eye, V. is equally good if Ac. is sufficient and active ; the eye being made practically H., the Ac. is exerted in order to neutralize the excess of Cc. power. For instance, a young myope may see equally well through – 2, – 2·25, – 2·50 D. and many other stronger lenses, but sees less acutely with – 1·75 D. Therefore 2 D. is the measure of the M. because a weaker lens causes a lessened visual acuity, and a stronger one does not give any higher acuity.

Care must be taken not to excite Ac. and thus over-estimate the degree of M. ; this is always probable especially when there is As., and too much stress cannot be laid on the necessity of not increasing the power of the – sph. lens *unless definite ability to read smaller types is thereby obtained, and that such increase should not exceed some* 1/2 *or* 1/4 *D. for each line of the types.* The measure of M. is the power of the very weakest Cc. sph. lens with which the most acute vision is obtained *when both eyes are engaged in vision.*

Thus if with −2 D. V. = 6/4·5 for each eye separately, and binocularly V. = 6/4·5 with + ·25 D. added to each, then the measure of the M. is 1·75 D. (vide *Binocular Test*). Whether Ac. is exerted for distance or not can usually be learnt by noting if vision varies when the types are observed with lenses which cause it to be about 6/9 or 6/12.

Except in very high M. and in extreme old age, Ac. is never totally at rest, so that the degree of M. manifested under cycloplegia, is generally smaller than it is under ordinary conditions of sight; an eye which is ordinarily M. 1 D. would be more nearly Em. under atropine.

The Binocular Test is made, as in H. by applying pairs of weak + sph.'s when the two eyes are engaged, after each separately has been corrected to best possible vision. It sometimes occurs that, notwithstanding the precaution taken in the monocular test, equally good, and more comfortable sight, is obtained when the Cc. lenses are thus reduced in power. Additional − power cannot be needed in binocular vision, although one might think that this is a possibility, from a theoretical aspect, in high exophoria.

Fogging Lenses.—Fogging is resorted to in order to reduce accommodative action. It is not unusual to find Ac. apparently increasing the degree of M. and, to fog, it is merely necessary to give lenses which under-correct the apparent error, these having the same effect as over-correcting Cx. lenses in H.

Testing and Correcting of M.—In theory the correction would be those Cc. sph.'s which fully correct the optical error, but in practice we find that the lenses needed vary quite considerably with the degree of error, the muscular balance, the accommodative power and the visual necessities of the myope. In H. the selection of the needed lenses is much simplified by the fact that, excluding presbyopia, the same serve for near and for distant vision; in M. more often than not the contrary is the case. In the following it is presumed (*a*) that the age precludes presbyopia, (*b*) that there is no As., (*c*) that normal V. is attained, (*d*) that the eyes are healthy.

The measure of the M. is obtained by the distance test; the near test then follows, and those lenses which are best suited for near work are prescribed for *constant* wear. They must allow of close work being done at a sufficiently great distance without undue strain on the Ac. and, therefore, weaker lenses are generally needed than for distance because the accommodative action is lessened in M. At the same time Con. is more easily exerted if it is accompanied by Ac. When Con. = 3 M. A., an associated and equal effort of Ac. produces a certain quantity of that function; now if this quantity were 3 D. the myope could, with comfort, wear his full correction for close work, but if, as is usually the case, the quantity is less, his full correction must be reduced for near vision. Such reduction may be anything between ·25 D. and 3 D., but the latter rarely occurs except in very high M., or where there is high Eso.

The lenses used in near vision are of greater importance than those for distance; they increase the distance at which reading, etc., is done, so that not only is the actual amount of Con. lessened, but it is more easily effected owing to the associated Ac. which is rendered necessary by the Cc. lenses themselves; they thus relieve strain on convergence, they render the maintenance of binocular vision possible, they harmonize Ac. and Con., cure or prevent, as the case may be, asthenopia, headaches, heterophoria and strabismus, and they tend to prevent increase of the M. For instance, a myope of 6 D. without correction would read at his P. R., which is at 16 cm., employing 6 M. A. Con. and no Ac. With, say, − 5 D. lenses, he would read at, about, 33 cm. where Con. is only 3 M. A. and Ac. = 2 D. Not only are 3 M. A. Con. more easily effected than 6 M. A., but the stimulus, lacking when Ac. is not exerted, is no longer absent.

The constant glasses given to a myope should be neither a full correction, nor too great an under-correction. The first causes too great a demand on Ac. so that the necessary effort made, in order to see, would produce discomfort, would stimulate Con. too much, and would cause print to appear small, so that the latter may be approached to the eyes to increase the size of the retinal image. Thus not only do the glasses cause strain on all the muscles, but they bring about what they are intended to prevent, namely, reading at too short a distance. On the other hand, under-correction causes too small a demand on Ac. and fails to remedy sufficiently the defect and its attendant troubles. Lenses prescribed should prove comfortable so soon as they are taken into use. The optician should resist any desire of the myope for acute distant vision associated with reading, without lenses, too near to the eyes.

Since the constant use of Cc. lenses renders Ac. necessary, a depleted accommodative function, in a young myope, may be gradually raised to a normal state. If non-use lessens the functional activity of the ciliary muscle, use should increase it, and, where a reduced correction has to be given, a judicious treatment of the case, by very gradual increase of power, may result in the course of time in a full correction being worn with ease and comfort. When full correction for near work seems possible, it is well to note that the near point, with lenses, is at least as near to the eyes as it would be with an emmetrope at the same age. If it is not, full correction for all distances is contra-indicated. It should be always remembered that an apparently full correction may be actually an over-correction if there is any spasmodic Ac. and, in short, it is safer to leave part of the apparent defect uncorrected.

The writer thinks that generally M. in children younger than, say, 16 should be measured under cycloplegia because some cases need *full* correction but never *over*-correction, and it is practically impossible to obtain the exact true measure of the error without the use of drugs.

Although low, medium and high M. are, in the following paragraphs, treated separately there is no sharp division between them and rules generally, with modifications, are common to the three.

Low M.—In M. up to about 3 D., lenses with which V. = 6/9, should be worn constantly by young people, except perhaps when at play. Quite apart from the other important effects of the lenses, constant use of the correction by a school child is indicated, because it would be difficult for him to put his glasses on and off as he views alternately the blackboard and his copy-book. When maturity is reached a full correction may be given with greater confidence, provided comfort is obtained in close work. Many adults, who have not previously used concave lenses, prefer to read without them. This is permissible in low M. and is the more so as the error is low. In these cases the glasses are required for distant vision only, they being put on when far objects have to be seen and taken off for close work. Where, however, asthenopia is present, as indeed sometimes occurs even in very low M., constant use is indicated, as it is also when close work is brought too near the eyes, and when close work is as comfortable, or more so, with the glasses than without them. Also when there is As. or anisometropia, although frequently these cause no trouble to adult myopes. When under-correction is given to an adult for constant wear, a full correction may be also given for distance only.

Medium M. ranges between 3 D. and 6 D., but in children such degrees must be considered respectively high and very high, and require great care in their treatment; in some cases rest in the form of partial or total abstention from close work being indicated. Rules which tend to prevent increase must be rigidly enforced and the child's eyes kept under observation for a few years.

At all ages, although reading and writing can be easily performed without lenses, the working distance is too short. The distance correction having been found, No. 1 type on the hand card will be easily read with the same glasses if the accommodative power is good. If this be the case the power of the lenses should be but slightly reduced, say, ·5 to 1 D. and these given for constant use. If with the distance glasses, No. 1 type cannot be read, or only with difficulty, the reduction in power must be greater, say, 1·5 D. or 2 D. or even more; it should, however, always be as small as possible and should not reach 3 D. for 33 cm. or 2·5 D. for 40 cm. because in that case no Ac. at all is used when reading, a condition which is not desirable. The lenses should enable the myope to read fine print comfortably at the reading distance and the latter should not be nearer, in any case, than 33 cm. or, preferably 40 cm.; this correction should be employed constantly. Rarely is there left uncorrected more than, say, 2 D. of M. and in many cases it is less. Where full correction cannot be constantly worn by an adult, this may be supplied for occasional use, as for the theatre, shooting, billiards, etc.

High M.—The selection of the required lenses is in general the same as for medium M., the only difference being that the reduction for constant wear would probably need to be higher, the accommodative power being frequently very depleted. Also, in very high degrees, it may be necessary to bring the reading distance nearer to the eyes than 33 cm. so that a still greater reduction may be required. In some cases of high M. (6 D. to 10 D.) or even very high M. (over 10 D.) the V. A. is normal and Ac. good, so that the selection of the lenses needed may be on the lines indicated for medium defects. In other cases V. is lowered, Ac. is bad and the eyes generally are difficult to correct; the optician must make quite sure that medical treatment is not needed in preference to, or along with, optical treatment, before he takes the responsibility of treating them.

Exophoric and Esophoric M.—The excessive Con. demanded in M. and the deficient innnervation due to the lack of stimulation from the Ac. produce exophoria or insufficiency of the internal recti; it is the muscular condition usually found associated with M. The difficulty experienced in Con. is remedied partly by exciting Ac. with Cc. lenses and partly by removing the near working point to a greater distance where less Con. is required. The rule in exophoric M. is to fully correct the M. in the sense that the *constant* wear and *reading* glasses should be as *nearly as possible equal* to those for distant vision. By this means the Ac. effort is increased to more nearly harmonize with the reduced Con. effort necessary. As already stated, lenses somewhat weaker than full correction must, almost of necessity, be given on account of the small amount of Ac. produced by a given effort; lenses which are too strong may cause the Ac. effort to exceed that of Con.

Esophoria, or insufficiency of the external recti, is the exception in M. When it is present only a relatively small Con. effort is required, so that if Ac. be induced by Cc. lenses, the Ac. effort is greater than that of Con. and reading and near work is achieved with difficulty and pain. The remedy consists in giving such lenses for constant use and near vision as cause *very little* or *no* Ac. to be exerted, *i.e.* the distance glasses must be *considerably reduced* in strength, say, 2 D. to 3 D.

Comfortable vision results from harmonizing, not necessarily the quantities, but the efforts of Ac. and Con. Between Exo- and Eso- there is Ortho-phoria which demands for the M. a correction modified so far as the accommodative action is lessened for a given effort. The muscular balance is an important factor in the estimation of the needed correction in M.

The Reasons for Corrective Lenses.—Summarizing what has been previously said, lenses are given in M. because they improve the sight for distance, and may be for close work; they enable close work to be done at a greater distance, they relieve Con., harmonize Ac. and Con., and maintain binocular vision; they prevent or cure asthenopia, photophobia, heterophoria, squint, etc., and most important of all, they prevent an increase of the defect. The defective shape of the globe cannot be remedied nor, as in H., can it diminish in degree except from operation, disease or old age. All that can be done is to make the eyes *more or less practically Em.* by means of lenses, and prevent increase by optical and hygienic treatment. M. cannot be reduced or cured by lenses, although some may think that this has occurred owing to a previous erroneous measurement of the refractive condition.

Reasons for the Acquisition of M.—It is known that M. is not congenital, but acquired from excessive increase in the length of the globe. It is not, however, known why some people become M. and others not, although the influence of heredity in this connection is acknowledged; the children of myopic parents have a tendency to acquire M. in the same way as the children of tall parents are likely to grow tall. The probable reasons for the abnormal development which results in M., may be divided into those natural to the eyes themselves, and those connected with the way in which they are used.

The use of the eyes in close work is the predominant cause of M. The eyeball in childhood is soft and yielding, and continued convergence with its accompanying tension of the motor muscles on the globe, tends to lengthen it in the region of the posterior pole, where the resistance of the sclerotic is a minimum. Further, if excessive innervation of the internal recti is accompanied by restraining action of the external recti. the globe is compressed between them and tends to become egg-shaped, This would obtain so long as the demand on Ac. exceeds that on Con., and the tendency to lengthening of the globe being established, would continue even when Ac. in excess of Con., is no longer requisite for clear binocular vision. It is sometimes said that M., when neglected, feeds on itself and the expression is apt in that the increase of the defect itself calls into greater prominence those habits of Con., etc., to which it is due; in other words, there is a sort of vicious circle of cause and effect.

The greater the interpupillary distance, the greater is the actual amount of Con. needed for any given distance and the action of the internal recti is thereby increased. Whether it be a coincidence or not, it is frequently the case that myopes have large interpupillary distances and the deduction may be drawn that a great distance between the two eyes rather tends to the acquirement of M.

There is a decided tendency to develop M. where there is any condition of the eyes, as nebula of the cornea, irregular As., cataract, etc., which, by reducing the visual acuity, necessitates the holding of small objects close to the face. These conditions are, however, comparatively rare, but regular As. is not and it is extremely probable that the chief factor in the acquisition of M. is uncorrected congenital As. When the latter is present and the faculty of sectional Ac. has not been developed, the retinal image is blurred and objects, such as print, can be seen only if the angle of vision is increased in order to produce a large retinal image and this action is the more easy in youth as the accommodative amplitude is then large. Cases of M. without As. are much less common than those with it.

Excessive Ac. is, by some, considered to be one of the causes of M.; its direct influence is not apparent but undoubtedly, by exciting excessive Con., with its corresponding antagonistic muscular action, it plays some part. Stooping over books and other work also has a marked adverse influence by causing the normal flow of the blood to be impeded, with consequent engorgement of the ocular vessels. There is not, however, any special tendency to the acquirement of M. by those, such as engravers, watchmakers, etc., who are continuously engaged in close work with the head in a stooping position. The explanation would seem to be that continuous application at short distances commences, in these cases, later in life. Besides, in such occupations a single magnifying-glass is employed and therefore Con. is not brought into action.

The foregoing causes are mainly embodied in continuous use of the eyes associated with stooping and undue approximation of the work. Consequently if near work be carried on under conditions favourable to them, it is far more likely that M. will result, when there is a tendency thereto. Such conditions would include bad or improperly placed lighting, desks too low or seats too high, print too small, reading by firelight or by flickering light. These obviously cause stooping or approximation of the work to the eyes and tend to produce M., even if there are no anatomical factors, and still more so if there are.

Whatever tends to produce M., in a H. or Em. eye, tends also to increase M. when it already exists. Moreover, that which at first may be merely a habit or a necessity, owing to uncorrected As. or a low desk or bad light, becomes respectively a necessity, or an increased necessity, when M. to any extent actually exists. That is to say, the myope indulges, under similar circumstances, in closer approximation to the eyes of the object viewed and in more stooping than does the H. or Em. A myopic child is the more likely to be addicted to reading and study and would follow these pursuits under conditions favourable to increase of the defect, and he is often less inclined to outdoor sports for the very reason that he has defective vision.

Hygienic Measures.—In addition to the use of corrective lenses, certain rules, respecting the use of the eyes, should be followed. They are specially applicable to children or where the M. is of high degree or where it is, or is likely to be, progressive. They are all formulated with the object of preventing an increase of the defect and incidentally they help to cure asthenopia and other troubles.

The light for reading, writing, etc., should be bright and steady and when writing should, for preference, be on the left but certainly not on the right as then a shadow of the hand interferes with vision. No close work should be done without the prescribed lenses, nor in a dull light nor for any lengthy period without a reasonable rest therefrom; the habit of momentary relaxation obtained by looking to the other end of the room should be encouraged. No close work should be done when lying down, as this puts increased strain on the motor muscles, nor when walking, driving or under any condition where the distance of the object viewed is constantly changed. Near work should be limited in extent, and, for children, plenty of outdoor exercise recommended. Nothing tight should be worn round the neck; habits of stooping and close viewing must be broken; writing and reading at a reasonable distance, with the head erect, must be insisted on. If M. is really progressive in the sense that, notwithstanding correction and attendance to rules, the defect increases and within, say, six months, calls for higher power lenses, the abstention from close work should be lengthened and, if necessary, made complete for a period.

The Visual Condition of M.—Malignant, progressive or very high M. is an extremely dangerous condition of the eyes; medium or high M. also presents many inconveniences, troubles and disadvantages. Low M. when it has become stationary is, however, a state which has, at least, as many advantages as disadvantages. Distant V. is not acute, but objects, as a rule, are sufficiently well seen; indeed, to a myope of low degree, the view of his surroundings is softer and more pleasant than to the Em. At the same time he can obtain acute vision, if he wishes to, by using glasses. His near vision is exceedingly good and strong, and he can maintain close work without fatigue for a much longer time than can the Em. or H. Finally, the period of life when reading glasses are a necessity is long delayed and this is no small advantage. That low myopes prefer their slightly blurred or softened natural vision to the more crude and sharper image obtained with lenses, is evidenced by the fact that they either do not constantly use glasses or they prefer under-correction.

M. and Acquired H.—The same changes due to age take place in M. as in Em. and H. Consequently, at about 50 years of age, or a little later, the refractive condition of the eye and therefore the degree of M. commences to decrease, the acquired H. partially neutralizing the original M. In theory a degree of M. as high as 2·5 D. may disappear, but there are few statistics to show how far it is the case that M. in old age becomes Em. or H.

M. and Presbyopia.—Since Ac. decreases with age, Cc. reading glasses must then be reduced in strength. If the presbyopia equals the M. no glasses are needed for reading; if the presbyopia exceeds the M. the glasses required for reading would be Cx. while those for distance would be Cc. No Cx. lenses can be required if the M. is 3 D. or more, for the myope can then always read at his P. R. But, allowing for decrease of M. in old age and approximation of the reading place owing to reduced visual acuity, the limit degree of M. in middle age which can never need Cx. lenses for reading in extreme old age, would not be less than 5 or 6 D. Constant Ac. action tends to keep that function active and delays the advent of Pres.; consequently the constant use of reading glasses, of a power approaching full correction, serves to keep the myope from becoming presbyopic until a more advanced age.

M. and Aphakia.—If the crystalline be extracted, the refractive power of the eye is decreased by the power of the lens which, *in situ*, is some 16 D. The whole dioptric system is, however, altered and becomes a refracting body of one surface, whose principal point is advanced to the cornea and whose nodal point slightly recedes. A previously M. eye becomes H. unless the original M. was so great that the axial length is equal to, or greater than, the posterior focal length of the cornea, *i.e.* 32 mm., which corresponds to a M. of about 20 D. (see *Aphakia*). Cure of very high degrees of M. has been attempted by extracting the crystalline. By some it is stated that results have been satisfactory and by others the reverse; it is probable that a sufficient number of these operations have not been made to settle the question of their desirability. Surgeons may prefer the evils with which they are acquainted to those which may arise from the operation, and certainly there seems to be increased liability to retinal detachment after extraction of the lens.

Divergent Strabismus.—If the harmony between Ac. and Con. be broken the M. exerts less of the former than of the latter and can obtain clear near vision without squinting, but should harmony be maintained, there must be either clear vision of one eye and a divergent squint or indistinct vision and no squint. When M. is the cause of divergent strabismus, its cure is essentially the use of Cc. lenses (vide *Strabismus*).

CHAPTER VII

ASTIGMATISM

Derivation.—*α*, without; *στιγμα*, a point.

Astigmatism is caused by unequal regular curvature, or irregular curvature, of one or more of the refracting surfaces. It may, therefore, be regular or irregular but, unless otherwise stated, the term As. with respect to the eye indicates the regular form, whether in this chapter or generally. Irregular As. is discussed later.

Regular As. may result from unequal curvature of the cornea or crystalline, from obliquity of the latter or from unequal ciliary action. Corneal may be augmented by lenticular As., or the latter may diminish or neutralize the former. Again, the principal meridians of the one body may be oblique to those of the other, the resultant defect as a whole, being one whose principal meridians differ from both the originals. Whatever its cause, rays of light diverging from a point cannot, after refraction, be again united in a point. but pass through two separated focal lines.

The shape of a surface possessing regular astigmatism is *toroidal, i.e.* similar to the shape of the toric surface of a spectacle lens. A familiar example is the side of an egg, or the bowl of a spoon, but it is probable that the shape of the astigmatic surfaces of the eye are not so regular as these examples in the sense that the increase of curvature from the minimum to the maximum meridians is not uniform. Notwithstanding, however, the total result is the same, the effect being to produce two focal lines at right angles to each other.

Illustration of As.—A + sph. ⬭ + cyl. held in front of a screen illustrates As. No matter where the screen may be, a point image of a point object cannot be formed on it, the focus consisting either of a line, an ellipse or a circle of confusion. As. due to obliquity is illustrated by the cylindrical effect produced by tilting a + sph. lens with respect to the incident light; the nature of the foci will be seen to be practically the same as that produced by a sph.-cyl.

As. Congenital or Acquired.—*Corneal* and *static lenticular* As. may be either congenital or acquired but usually the former. As. caused by *obliquity* would usually be congenital, but may be acquired from dislocation of the Crys. As. due to unequal ciliary action—*dynamic lenticular*—is acquired.

Meridians are planes at right angles to that of the equator, which mutually intersect in the two poles. For all practical purposes, the meridians of an eye may be regarded as lines crossing each other at the vertex of the cornea. Viewed from the front, they are imaginary diameters of the corneal circle.

Angle Notation.—In the discussion of As., its determination and correction, standard notation is utilized; the various surfaces, as viewed from the front, are divided in a manner similar to that of the circle in trigonometry. The notation in degrees commences on the (observer's) right-hand extremity of the horizontal line and passing upwards (anti-clockwise) to the vertical, continues downwards to the horizontal again; thus the Ver. corresponds to 90° and the Hor. to 0° or 180°. Only the upper half needs to be notated, because any meridian or diameter corresponds to two continuous radii.

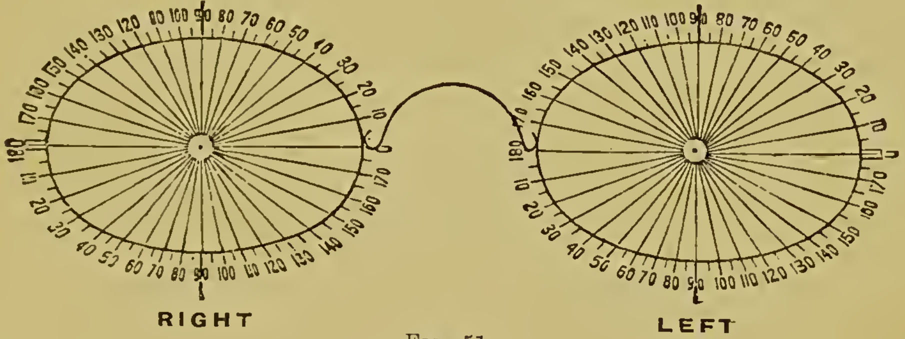


Fig. 51.

Thus 5° and 185°, indicate the same meridian, as well as 45° and 225°, 90° and 270° etc. The notation is the same for both eyes, so that 0° is at the nasal side of the (subject's) right eye, and at the temporal side of the left. If the notation is indicated on the lower halves of the circles, it commences on the (observer's) left, *i.e.* on the temporal side of the right and on the nasal side of the left eye, and proceeds downwards. Right and left of the subject and of the observer are contrary to each other and must, therefore, not be confused.

The Condition of As.—As. is usually corneal but even if due to the static condition of the Crys. it is unnecessary to distinguish between the two, so that no special reference need be made as to which of the surfaces is the seat of the defect. As. of the cornea, but not of the crystalline, can be detected by the ophthalmometer or similar instrument. The normal cornea and crystalline are spherical in curvature, so that light diverging from a point object on the axis is brought to a point image, the rays being equally refracted in the various Mers. through which they pass. If, however, the curvature of the cornea or crystalline should vary in the different Mers. the focus of a point source of light consists of two lines—called the focal lines—through which passes all the light, from that point, entering the eye. It is clear that As. cannot be corrected by a sph. lens since this possesses equal power in all its Mers.; the correcting lens must have a cylindrical element so as to form line and not point foci. Regular As. cannot exist in any one Mer.; it is a condition of the eye as a whole, and the *degree of As.* is essentially the difference between the refracting power of the greatest and least curvatures.

Light Refracted by an As. Eye.—The conditions are precisely the same as with a + sph.-cyl. lens. Let us consider the back of the eye removed, and let the Ver. Mer. be that of greatest refracting power. Light from a point at ∞ on the principal axis is converged to pass through a Hor. line F_1 (Fig. 52) in the first focal plane. From F_1 the rays proceed divergently in the Ver. and convergently in the Hor. plane, to meet again in a Ver. line F_2 in the second focal plane. The distances of the two lines behind the principal plane vary inversely with the dioptric powers of the principal Mers. The interval between the two lines, *i.e.* the interval of Sturm, depends on the difference between the two principal refracting powers, that is on the amount of As.; the interval is small in low, and great in high As. The lengths of the two lines depend on their distances behind the refracting plane and on the effective aperture of the eye, that is practically on the size of the pupil; if this is of pinhole size they are very short. Also their lengths depend on the interval between them, so that, if the interval is small, they are short and approximate more to points. A section of the light refracted by an As. eye is, at any place, an ellipse which is exaggerated into a line at two planes and into an almost complete circular disc at some one plane situated between the two focal lines. The two axes of such an ellipse are always in the same meridians as the focal lines. The calculations involved in determining the position and size of the lines and disc will be found in another chapter.

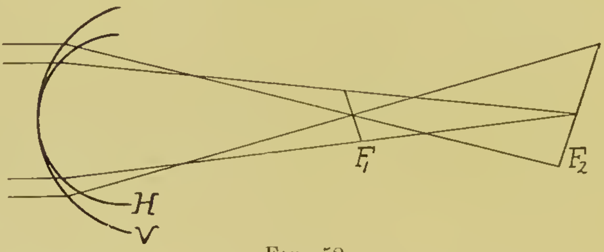


Fig. 52.

Principal Meridians.—Those Mers. of an As. eye possessing the highest and lowest degree of refracting power are termed the *principal meridians.* They are invariably at right angles to each other, and in testing and correcting As. these only need be considered. The focal lines correspond to the principal Mers., each of the lines being at right angles to the Mer. of which it is the focus. Thus if the principal Mers. are Ver. and Hor. the image of a point is for the Ver. Mer. a Hor. line, and for the Hor. Mer. a Ver. line. Since the principal Mers. are at right angles, if the one be located the position of the other is also known. For instance if the one is 40° the other is at $40 + 90 = 130°$; if the one is at 175° the other is at $175 - 90 = 85°$ and so on.

A section made in a principal meridian of an astigmatic surface like the cornea would be spherical, whereas a similar section oblique to the principal meridians would be elliptical. It may be said, therefore, that an astigmatic surface consists of two different spherical curvatures mutually at right angles, between which are an infinite variety of elliptical curves ranging from the minimum to the maximum principal meridians.

The Optical Condition of As. is one of unequal refraction. Both principal Mers. may be H., or both may be M., to different degrees; the one may be Em. and the other H. or M.; finally, the one may be H. and the other M. In any of these cases, if the difference between the two principal Mers. is, say, 2 D., there is an As. of 2 D. which is precisely the same whatever may be the optical condition of the individual principal Mers. An As. of 2 D. is corrected by a 2 D. cyl. which may be either Cx. or Cc., the axis of the + lens being placed to coincide with the Mer. of greatest power, while that of the − lens would need to coincide with the Mer. of least power.

If the principal Mers. of the cornea have radii of, say, 8 mm. and 8·5 mm., or of 8 mm. and 7·5 mm., there is As. present and it is obvious that this differential refracting power may be present with a normal, excessive or deficient length of globe. In other words, an optical error due to the length of the globe, is quite independent of any astigmatism that may exist and *vice versa*, so that when considering astigmatism in the abstract, we can only speak of it as a *difference* in power and not as a positive or negative defect as is M. or H.

Classification.—In an eye having, say, 2 D. greater power in the one meridian, *the position of the retina, with respect to the focal lines, determines the class of As.*, or rather the name given to it. Thus when the retina (Fig. 52) is

beyond F_2	there is	compound M. As.
at F_2	,,	simple M. As.
within F_2 beyond F_1	,,	mixed As.
at F_1	,,	simple H. As.
within F_1	,,	compound H. As.

In the following F_1 and F_2 are the 1st and 2nd focal lines respectively and M_1 and M_2 the corresponding principal meridians.

Simple H. As.—M_1 is Em. and F_1 is at the retina, M_2 is H. and F_2 is behind the retina; a + cyl. will advance F_2 to the retina. Thus with Em. at 90° and H. 2 D. at 180° the correction is +2·0 C. Ax. 90°.

Compound H. As.—M_1 is H. and F_1 is behind the retina; M_2 is more H. and F_2 still farther back; a + cyl. will advance F_2 to F_1 and a + sph. will advance the united image to the retina. Thus if there is H 2 D. at 90° and H. 3 D. at 180° the correction is +2·0 S.⌓+1·0 C. Ax. 90°.

Simple M. As.—M_1 is myopic and F_1 is in front of the retina, M_2 is Em. and F_2 is at the retina; a – cyl. will carry F_2 back to the retina. Thus if there is Em. at 180° and M. 2 D. at 90° the correction is –2·0 C. Ax. 180°.

Compound M. As.—M_1 is myopic and F_1 is in front of the retina, M_2 is less myopic and F_2 although also in front, is nearer to the retina; a – cyl. will carry F_1 back to F_2 and a – sph. will carry the united image to the retina. Thus if there is M. 2 D. at 180° and M. 3 D. at 90°, the correction is –2·0 S.⌓–1·0 C. Ax. 180°.

Mixed As.—M_1 is myopic and F_1 is in front of the retina, M_2 is H. and F_2 is behind the retina; a – cyl. will carry F_1 back to the retina and a + cyl. will advance F_2 to the retina. Thus if there is M. 2 D. at 90° and H. 3 D. at 180°, the correction is –2·0 C. Ax. 180°⌓+3·0 C. Ax. 90°. In practice, of course, the latter combination would be transposed into a sph.-cyl. which would also be used in actual testing.

Variations in the Class of As.—Compound H. As. may become, as the eye grows in length, simple H. As., then successively mixed As., simple M. As. and, finally, compound M. As. Again, any of the latter may become compound H. As. owing to acquired H. in old age. Generally the class of As. may vary, if the total error is not high, as Ac. is more or less exerted and this not only in the course of years, but from day to day or moment to moment. Suppose a case corrected by –·25 S. ⌓ –·50 C. Ax. 180°; here is apparently compound M. As. If Ac. relaxes ·25 D. it becomes simple M. As. and if, with further relaxation, successively +·25 D., +·50 D. and +·75 D. sphs. are accepted, the class of As. would be designated respectively mixed, simple H., and compound H. As. Whatever the class, the As. is ·5 D.

Dynamic Lenticular As., as to the existence of which opinion is divided, is As. of the Crys. caused by unequal ciliary action; it is also termed *sectional* or *astigmatic* accommodation.

Suppose an eye to be H. 1 D. in the Ver., and H. 2 D. in the Hor. Mer. If no Ac. is exerted, both focal lines are beyond the retina; if 1 D. or 2 D. Ac. is exerted, the one focal line is at the retina and the other, respectively, behind or in front. With Ac. between 1 and 2 D. the retina lies nearly in the circle of least confusion, about midway between the focal lines. Those who deny the existence of sectional Ac. suppose the eye to be adapted for this position, because it is frequently the case that, in low compound H. As., no difference in the lines of the radiating fan is noticeable.

There seems, however, to be ample proof of the existence of sectional Ac. For instance a Cc. cyl. of the correct strength cures asthenopia caused by any class of As. yet with the lens, more general Ac. may be used than without it. Without a sph. lens the manifest As. is frequently lower than that shown when the eye is *fogged* and although in early life there may apparently be no As. yet this becomes manifest later on, or the original amount is increased. Some old people whose V. is improved by cyls. for distance actually see better without them for reading; here the defect is manifest for distance because the Ac. is dormant, but when the latter is exerted for reading it automatically corrects the error; also the use of atropine frequently unmasks As. which, without it, is latent. In simple and compound H. As., astigmatic together with general Ac. may render V. normal for all distances. In low mixed As. it renders the eye M. by bringing the back focal line up to the front, and the same occurs in simple M. As.; while in compound M. As. it causes general M. of the higher degree. In the myopic cases distant V. is not improved by sectional Ac. its only effect being to make near work possible or easier and, therefore, no doubt it usually occurs only in near V.

Myopes with As. who select lenses for themselves generally choose, if they have good Ac., sphericals which represent the higher degree of M. or even still stronger ones. These lenses produce H. which again is corrected by Ac. exerted more in the one principal Mer. than in the other. The same may result if the eye be tested on the principle that the weakest – sph. *which gives best vision* is the measure of the M.; such a lens usually overcorrects the error common to both principal Mers. Of course, sectional accommodation can only neutralize or mask a low degree of As.; in the high defects it is not exerted and the astigmat resigns himself to deficient distant vision and manages to read by bringing print close to the eyes so that a large retinal image is obtained.

As. With and Against the Rule.—Normally the cornea, which is the chief refracting body of the eye and the chief seat of As. has a greater Ver. than Hor. curvature. Therefore As. is *with the rule* when the refracting power of the eye is greater vertically than horizontally and it is *against the rule* when the contrary occurs. In As. with the rule the axis of the correcting + cyl. is Ver. or nearly so; that of a – cyl. is Hor. or nearly so. In As. against the rule the axis of a + cyl. is approximately Hor.; that of a – cyl. is approximately Ver. Some include in As. with the rule all cases where the meridian of greatest power is within 40° on either side of the vertical, and in As. against the rule those cases where it is within 40° on either side of the horizontal. When As. is chiefly due to the crystalline it is more likely to be against the rule.

Normal As.—Every cornea is said to be As. but sometimes to so small an extent as not to call for correction. Such As. is regarded as normal and does not exceed ·25 D.; the same applies to the Crys. Normal As. of the cornea *with the rule* may be neutralized by normal As. of the Crys. *against the rule*, but resultant As. of the eye less than 1/4 D. is regarded as normal.

Acquired As. may result from a wound or operation involving the cornea. In an operation for cataract a section of the upper portion of the cornea is made and when the latter re-unites the vertical curvature is lessened; the resultant As. is *against the rule*. Acquired As. may increase, decrease or neutralize original corneal As. and extraction of the Crys. removes the influence of the latter—static or dynamic—on the general As. of the eye.

Symmetrical and Asymmetrical As.—In accordance with the general law of symmetry of the body, the principal Mers. in As. are similarly inclined towards the median line. Thus the meridian of greatest or least refraction are, as a rule, both Hor. or Ver. or both equally inclined outwards or inwards. Thus in *symmetrical* As. the axes of the two cyls. are similarly symmetrical and it is very rare to find a case where the two cyls., *when of the same sign*, are required asymmetrical, *i.e.* more or less parallel. The foregoing, of course, applies to the general inclination and does not mean *exact* symmetry. The few exceptions to the above occur principally in high anisometropia, and are usually accompanied by considerable general asymmetry of the face.

Nomenclature.—It is usual to refer to As. according to the direction of the axis of the correcting cyl. or to the angular position of the Mer. which departs least from the normal. Thus if a cyl. is needed with its axis Ver., Hor., or oblique, the As. is referred to as Ver. Hor., or oblique respectively. These correspond to the direction of the bar of the As. chart which theoretically is seen most blurred. Thus vertical As. means that corrected by a cyl. axis 90° or thereabouts.

Variations in the Degree.—Congenital As. of the cornea is presumed to be constant, but as it is often found to have changed, or apparently so, within a comparatively short time, there is some doubt as to its fixity. Corneal As. caused by operations is usually at first rather high, but rapidly diminishes and may even totally disappear. Variations may also occur in the As. of the Crys., but, quite apart from physiological reasons, apparent changes in the As. of the eye as a whole may arise from various optical sources, as follow.

There is the change due to effectivity as the cyl. is placed in advance of the cornea and as it is Cx. or Cc.; this then causes the subjective measure of As. to differ from the ophthalmometric, so that, say, 4 D. corneal As. is corrected by a − 4·25 D. cyl. or a + 3·75 D. cyl.

There is the change of the astigmatic value of any cyl., as this is combined with a sph., or with some other sph., power as the case may be. Thus a degree of astigmatism measured in the eye or on the cornea, as by the keratometer, is different from the power of the cylindrical which will correct it when the latter is combined with a spherical. For instance if there is found 4 D. actual corneal As. there would be required, if the one Mer. of the eye is Em., a cyl. lens of focal power +3·75 D. or −4·25 D. Suppose, however, as in aphakia the one Mer. is H. 12 D. and the other H. 16 D. the focal lengths of the lens would need be approximately 85+15=100 mm. and 62·5+15=77·5 mm., or powers of +10 D. and +13 D.; that is, +10 D. sph. ⬭+3 D. cyl. In M. 14 D. and 18 D. the lens would need be about −18 D. and −25 D.—that is, −18 D. sph. ⬭− 7 D. cyl.

A similar effect results when testing. Suppose an eye be fogged with a +sph. lens and the As. exactly corrected by a −cyl. so far as the appearance of the chart lines is concerned. When the +sph. is reduced in power to obtain the highest V. A. the slight change in the effectivities may cause the two sets of bars to be no longer equally clear when so delicate a test as the Orthops diamond is employed. Some slight changes in the power of the required cyl. occurs even as Ac. is exerted or relaxed in distant vision. Also the cyl. alters as the needed sph. changes with age.

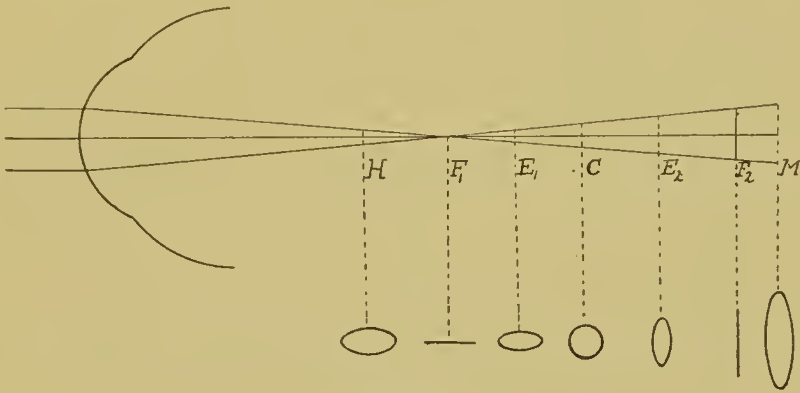


Fig. 53.

The chief changes, however, result from nearness of the object viewed, *i.e.* when the cyl. selected for distance is employed in near vision, for then the divergence of the light causes variations in the effectivity not only of the cyl., but also of the sph. with which it is combined. With very strong cyls. this may sometimes need attention and the subject is considered in Chapter XVI.

The subjective measurement may differ from the ophthalmometric tests of corneal As. on account of the influence of the crystalline, but there seem to be no reliable statistics on which can be based any rule for judging the usual nature of lenticular astigmatism. It has been fairly definitely proved, however, that the latter is rarely so high as to modify, to any great extent, the corneal As., and the principal meridians, as found by the ophthalmometer, rarely differ from those found subjectively.

Vision of a Point and of a Line.—Suppose that, in an eye, the first focal line is Hor. and the second Ver. and a *single luminous point* be viewed. Then the shape of the image depends on the position of the retina in the refracted astigmatic pencil (Fig. 53), as follows:

Position of Retina.	Class of As.	Retinal Image.
At M	Compound M. As.	A Ver. ellipse
At F_2	Simple M. As.	A Ver. line
At E_2	Mixed As.	A Ver. ellipse
At C	Mixed As.	A circle
At E_1	Mixed As.	A Hor. ellipse
At F_1	Simple H. As.	A Hor. line
At H	Compound H. As.	A Hor. ellipse

If the retina is in the second focal plane, a Ver. line object is seen sharp although slightly extended, but a Hor. line would be seen blurred; for a Hor. line to be seen clearly the retina would need be in the first focal plane. When the retina is between the focal planes, both Ver. and Hor. lines would be blurred, the Ver. line being expanded horizontally and the Hor. line expanded vertically. Oblique lines would be seen confused for any position of the retina of such an eye. If the same eye views a square object, the top and bottom edges would be seen sharply while the sides would be blurred when the retina is at F_1, and the reverse occurs when it is at F_2. When the retina is between F_1 and F_2 both edges are blurred more or less and if the square were rotated so that the four edges are oblique to the principal Mers. of the eye, they would be seen blurred no matter where the retina may be.

Therefore, in an As. eye, *the perception of a line is good if the direction of that line corresponds to the direction of the focal line which is at the retina*, and it is fairly well seen if it corresponds to the long axis of an ellipse at the retina. The perception of a line is correspondingly bad if its direction is at right angles to the retinal line or ellipse.

Perception of Radiating Lines.—The last article explains why As. is determined if one sees some of the bars of a radiating fan more clearly than others; the bar most clearly seen and the one that is most blurred, correspond to the principal Mers. of the eye.

Suppose the two principal Mers. to be Hor. and Ver. and the object viewed be an upright cross. The light diverging from *any* point on *either* of the limbs enters the eye in every Mer. as a diverging cone, and there is no difference in the refraction which the light undergoes *wherever* the object point be situated. The image of any point of the cross consists of two focal lines with the accompanying discs of confusion as in Fig. 53.

If the retina is situated at, or near to, the Hor. focal line, the confusion discs at the retina correspond in direction to the horizontal limb of the retinal image itself so that the edges of the Hor. portion of the cross are seen sharp and clear. On the other hand the Hor. confusion lines are at right angles to the Ver. limb of the retinal image, thus causing the edges of the Ver. portion of the cross to be seen blurred as shown in Fig. 54. If the retina were situated at, or near to, the Ver. focal line, the Ver. part of the object would be more clearly seen as in Fig. 55. If the As. is oblique, both limbs of the cross are blurred (Fig. 56) wherever the retina may be. The sketches illustrate the conditions when the retina is at the focal lines. More often the image of every point of the object is an ellipse but the same arguments apply as to why the one line is seen clearer than the other.

The Astigmatic Chart and Eye.—Let the As. chart be presumed to consist of only two lines or sets of lines, at right angles to each other, as on the diamond-shaped dial of the Orthops chart. When these correspond to the direction of the focal lines of the eye, the one is seen clearly and the other blurred. In theory there is only one position of best vision for a chart line but in practice there may be some doubt, if the As. be low, between two positions 5° or 10° apart. As an illustration let an eye have simple M. As. of 2 D., the myopic Mer. at 45° and the Em. at 135°. When the chart lines are Ver. and Hor. they are both equally blurred; if now they be slowly revolved one lot becomes more and the other less clear, and when the radial lines are inclined at 45° they are seen distinctly, while the tangential lines are very blurred. This occurs because, in the eye, the focal line at 135° is situated in front of the retina while that at 45° is at the retina. The correcting cyl. carries the front focal line back to the other, so that, by their junction, point foci are formed at the retina; it is, in this case, – 2 D. C. Ax. 135°, the concave power being in Mer. 45°.

FIG. 54.

FIG. 55.

FIG. 56.

On the Orthops chart the notation of the radiating fan and of the circle enclosing the revolving dial, is laterally reversed, because the chart faces the eye; it is further reversed through 90° so that the indicated direction of the lines, most clearly seen, gives the numerical position of the axis of the correcting cyl. in a frame graduated to standard angle notation. Thus no calculations whatever are needed when once the clearest position for the radial lines is determined. The points to be especially noted are:

(*a*) The clearest and most blurred lines of the chart correspond to the focal lines of the eye.

(*b*) The focal lines of the eye are at right angles to the Mers. of which they are respectively the foci.

(*c*) The clear chart lines correspond in direction to the Am. (or most Am.) Mer. of the eye; consequently the *power* of the cyl. is needed in this Mer.

(*d*) The blurred chart lines correspond to the Em. (or least Am.) Mer. of the eye. Therefore *the axis of the correcting cyl. must be placed in a direction corresponding to these blurred lines.*

Thus for an eye corrected by − 2 D. C. Ax. 180°—

The Ver. Mer. is M. and the Hor. is Em.

The Hor. focal line is in front of the retina; the Ver. line is at the retina.

The Ver. chart lines are seen clearly; the Hor. are blurred.

The Ver. Mer. of the eye requires Cc. power; the Hor. requires no power; that is, the cyl. is axis Hor., and, with the cyl., both sets of lines are seen with equal clearness.

The direction of the principal Mers. and, therefore, that of the axis of the correcting cyl. is roughly determined by the radiating fan and definitely determined by a slight revolution of the diamond. It should be quite unnecessary, in ordinary cases of As., to rotate the cyl. in the trial frame.

Vision in As.—It is characteristic of uncorrected As. that some letters may be misnamed in several lines of the chart, so that it is difficult to define V. by a Snellen fraction. In low degrees of H. As. unaided V. is good and frequently quite normal, and corrected V. is very good. In high degrees V. is subnormal and may remain so when corrected although, as in absolute H. the use of corrective lenses improves it. In M. As. unaided V. must be subnormal but not to so great an extent as in M. of similar dioptral degree; corrected V. is very good.

In ordinary degrees of Compound H. As. or M. As. lenses should produce perfectly normal V. but the influence of H. or M. on vision, before and after correction, is the same as when these defects are not associated with As. In mixed As. unaided V. is bad and if of high degree corrected V. frequently remains subnormal. V. = 6/6 is possible with uncorrected low As. even if it is not masked by Ac. but when corrected it should be better than 6/6.

When the principal Mers. are Hor. and Ver., astigmatism does not cause real distortion, the images being merely more blurred in the one direction than in the other. Oblique As. causes distortion, but the mind ignores it and projects the images as if true; the astigmat does not conceive the upright sides of a house to be inclined obliquely, as they appear when viewed through an oblique cyl., that is, when artificial oblique As. is produced. On the contrary, when oblique As. is first corrected complaints may be made of distortion in the sense that straight lines look oblique. It is rather curious how an astigmat becomes accustomed to vision as it is to him; for instance, in Hor. As. it is quite natural that Hor. lines should be less clear than Ver. ones and it may cause surprise when it is learnt that there should be no difference in, say, the various lines of a mesh. The disadvantages from which astigmatic weavers, and similar workers, suffer, is considerable.

Vision is generally more reduced when the principal Mers. are oblique than when they are Ver. and Hor. because the outlines of most objects, including test types, are Ver. and Hor. Again, Ver. is worse for reading than Hor. As., the perception of reading type seeming to depend mainly on the upright limbs.

Symptoms and Effects of As.—As. causes reduced V. which is more marked in M. As. than in H. As. and, of course, as the defect is high. It causes also asthenopia, which even if ignored in youth shows itself later in life, say between 20 and 30. Asthenopia is more common in low than in high As. and more probable as vision is acute. Very severe asthenopia may result from a very low As. and the effect of low-power cyls. in curing it is often quite remarkable; nevertheless some cases, especially if myopic, whether lenses be used for distance or not, may never occasion asthenopia.

Asthenopia in high As. is caused by high demand on Ac. and Con., owing to the short distance at which near work is held, and in low As. by constant unequal Ac. (dynamic lenticular) or by constant change of action as the eye tries to adjust itself alternately for the one or other focal line. Possibly this latter results in clonic spasm of Ac. and its accompanying asthenopia. As. may be accompanied by frontal headaches, pain in the eyes, redness, etc., the symptoms being very similar to those caused by H.

In oblique As. the head may be inclined towards one shoulder; this is more general in near vision or when an endeavour is made to see clearly distant objects, as types during a test.

In high As. there is the common habit of partially closing the lids which, acting like a stenopæic, enables Ac. to be exerted to an extent suitable for the Hor. Mer. An astigmat using sph. power only, or an insufficiently strong cyl., may look through his glasses obliquely, thus obtaining a cylindrical, or stronger cylindrical, effect, as the case may be. Increased effect in the Hor. plane is obtained by looking sideways; in the Ver. plane by inclining the head or tilting the lenses—especially if these are mounted in pince-nez. Uncorrected As. is a great, if not the chief, factor in causing and increasing M. and causing spasm of Ac.

The Determination of As.—As. is practically determined when, on a certain line in the test types, some letters can be read and others not and is definitely determined if some of the bars of the As. fan are seen more clearly than others. The subject is asked which of the bars on the radiating fan seem blackest, or most distinct; if astigmatic, he sees best those in the middle, or those at the sides, or a group to the right or to the left as the case may be. This indicates roughly the direction of the one principal Mer.

The principal Mers. are obtained more precisely by the revolving dial of the Orthops chart; the pointer of the radial lines is turned to that Mer. indicated by the central bar of the group best seen on the fan. The pointer is then revolved a few degrees to the right and left of the primary position so that the subject may select that position at which he sees most clearly the group of radial bars of the diamond. This he is able to do, in the large majority of cases, so that the principal Mers. can be determined within 5°—or even less if necessary.

If, for instance, the group of lines on the fan round about 45° are seen most clearly, the pointer of the radial lines of the dial is turned to 45°; the latter are seen clearly while the tangential lines are blurred, indistinct and greyish. The diamond is revolved to 40° and 35°, and then to 50° and 55°, the subject selecting that position where the definition of the alternate white and black radial lines is most acute. This being selected, the two principal meridians of the eye are determined. The number indicated on the chart, by the central radial line is the position, in the trial frame, of the axis of the correcting cyl. whether this be Cx. or Cc..

When Ac. is active, determination of As. is difficult until the eye has been made, by means of a Cx. sph., slightly myopic, *i.e.*, *fogged;* when there is absolute H. this must be partially corrected or, better, over-corrected, before As. can be determined especially if the latter is low; where there is M. it must be corrected to about 2 D., or more, depending on the amount of As., before the latter can be determined. In mixed As. when the one defect is high compared with the other, As. is easily determined, but if the two elements are about equal its determination is difficult until, by employing a Cx. or Cc. sph., some of the fan lines become fairly distinct.

Where V. is good the difficulty in determining As. lies in the fact that, by accommodative action, the two focal lines have been united at or near to the retina; the remedy is to carry them forward, by a Cx. sph. lens, when they separate and the one lies nearer to the retina than the other. Where V. is bad, the difficulty lies in the fact that both focal lines are so far distant from the retina that nothing can be clearly seen. The remedy consists in carrying one of the lines to, or near to, the retina by means of a sph.

It is sufficiently accurate to determine the principal Mers. to 5°. A cyl. may be needed with its axis at, say, 40° or 45° but a position such as 43° can hardly be called for, so that fractions of 5° may be safely ignored.

The Measure of As.—Manifest As. is measured by the strongest + or weakest − cyl. that makes the radial and tangential lines of the diamond equally distinct at the same time. If there is difficulty in finding the measure of the As. it is generally because the eye is not *fogged* sufficiently Completely masked As. can be measured only when cycloplegia is employed. It frequently occurs that no cyl. produces equality of the radial and tangential groups of lines because while one cyl. is not quite strong enough, the next stronger one is too powerful. In this case it is better to give the weaker cyl. rather than to over-correct. Nor is a division of the diopter into fractions smaller than 1/4 D. necessary. The As. may be reckoned to be either, say, ·5 or ·75 D. but not, in reason, ·62 D. As. lower than ·25 D. may generally be ignored.

Any case of As. may be corrected, the principal meridians being equalized, by either a Cx. or a Cc. cyl.; the strongest + cyl. selected in one test, is the same as the weakest – cyl. selected in another test. If the one focal line lies behind the retina, it can be carried forward to the retina by a Cx. cyl. or partly by this and partly by Ac. but if the cyl. is too strong it is carried in front of the retina so that the *strongest* that equalizes the chart is the required lens. If the one focal line is in front of the retina, it is carried backward by a Cc. cyl. but one that is too strong tends to carry it behind the retina unless Ac. is exerted to prevent it, so that the weakest that equalizes is the required cyl. If V. is good a Cc. cyl. *too weak* or a Cx. *too strong* cannot well be selected when the As. bars are equalized, but a Cc. too strong or a Cx. too weak may be. In this connection cylindrical lenses do not differ from sphericals.

The Theory of Correcting As.—The theory of correcting any case of As. is to cause the eye to have *simple M. As.* so that the one focal line is at the retina and the other is in front of it. Since, however, it is difficult to be certain that the back focal line is at the retina without Ac. being exerted (apart from any latent H.), it is better in practice to convert the case into one of *compound M. As.* in which the general M. is of low degree. Then we have the one focal line just in front of the retina, the other some distance in front.

This is done in H. cases (simple or compound) by fogging with an over-correcting Cx. spherical lens, strong enough to place both focal lines in front of the retina; in simple M. As. by a very weak Cx. sph. and in compound M. As. by a Cc. sph. which under-corrects the M. The amount of M. produced by the Cx., or left by the Cc. spherical, is preferably ·5 or ·75 D. and Cc. cyls. are always employed. In this way and using the Orthops dial, which is specially designed for it, the *slightest over-correction must in every case* show by the originally blurred lines becoming the clearer because that focal line which previously lay farther out from the retina is carried nearer to it.

The lines originally seen most distinctly are not actually changed by a slightly over-correcting cyl. but the others become still more clear. If the cyl. strongly over-corrects so that the one focal line is, in theory, thrown behind the retina, Ac. takes place and the originally clear lines become blurred while the others are distinct because the former then lies farther away from the retina.

If the As. is so far over-corrected that even Ac. cannot bring the back focal line forward to the retina the relative clearness of the two sets of lines remains as before. This also occurs in the case of an old eye *when the one focal line is at the retina*, the originally blurred bars still are the more blurred on over-correction because H. As. is converted into myopic or *vice versa.* Consequently even in these cases, where there is no active Ac., it is as well to slightly fog for the correction of As.

We emphasize that for the true correction of As. fogging is needed and that when As. is slightly *over-corrected* the previously blurred bars of the diamond become more clear than the others; when under-corrected the originally clearer bars are still the clearer; when *just corrected* both sets are equally clear. Also that the principal meridians are those in which the radial and tangential lines are respectively *clearest* and most *indistinct.*

The As. is corrected by uniting the focal lines so that a point focus is formed, which is just in front of the retina, and finally this is carried back to the retina by means of a Cc. sph. Consequently the general rule is to always employ Cc. cyls. but in cases of high H. As. this procedure is sometimes difficult, if not impossible, to follow and the correction is best made by Cx. cyls.

The Testing and Correcting of As.—Generally all cases of As. fall under one of the following groups:

(*a*) Where there is H. with practically normal vision, that is 6/9 or better.

(*b*) Where there is H. with subnormal vision.

(*c*) Where there is M. with, of course, subnormal vision.

If there is H. with good V. the *strongest* + sph. is found which does not blur the sight; this represents the manifest H.; the V. is then fogged to 6/9, there being required for this purpose additional + power to produce an artificial M. of about ·5 D. The presence of As. and the principal Mers. being indicated by the fan, and the Mers. more exactly determined by the dial, a Cc. cyl. is placed in the trial frame, with its axis in that same numerical position as is indicated by the dial pointer. This will improve V, and the correcting Cc. cyl. selected by trial, is the weakest that makes the tangential (originally blurred) as distinct as the radial (originally clear) lines. A cyl. that is too strong will cause the tangential group to be more distinct than the radial.

After the cyl. is selected the + sph. is reduced in strength in order to improve vision, or increased in strength, if this be possible, so long as increased strength does not blur. This group includes low simple and compound H. As. and low mixed As. where the two defects are about equal. Thus if the ultimate + sph. is higher than the − cyl. it is compound H. As.;

if the + sph. is lower than the − cyl. it is mixed As.; if these are equal it is simple H. As.

If there is H. with subnormal V., which is improved by a + sph. the strongest is found which gives best V. and the latter is then fogged two or three lines by the application of an additional + sph. power. The principal Mers. are now determined and the dial placed in the position of correspondence with the principal meridians of the eye. The Cc. cyl. is then found and the + sph. reduced or increased in strength as described in the previous class. This group includes medium to high simple H. As., compound H. As. and mixed As., where the H. predominates over the M. according as, respectively, the + sph. is numerically equal to, higher than, or lower than the − cyl.

In As. with M. an attempt should be made to determine As. without improving V. beyond 6/36 unless, indeed, it be naturally better. If V. *could* be improved by − sph.'s beyond 6/36, it may, when not so improved, be regarded as fogged by under-correction, as it is in H. by over-correction; in the former the eye is left myopic and in the latter it is made myopic to certain extent. If no As. is manifested when V. = 6/36, it must be improved to 6/18 and again an attempt made to determine the As. If not determined when V. = 6/18, the sight is improved to 6/9 and the attempt repeated. If none be determined at any of these three stages it can be taken that the eye is free from As. The latter will be determined when V. = 6/36, 6/18, or 6/9 according as it is respectively high, medium or low. At whatever stage it is determined the Cc. sph. must be reduced to the weakest with which the one set of lines can be clearly seen, before cyls. are employed. When As. is determined the correcting Cc. cyl. is found as described for the other groups; finally if there is a Cc. sph. it must be reduced in strength if equally good V. is obtained, or increased in strength if improved V. is thereby obtained. If there is no Cc. sph., one may be wanted to attain a higher V. A. or a weak + sph. may be accepted without impairing the V. A. This group includes simple and compound M. As. and mixed As. when the M. predominates over the H. according as there is respectively no sph., a − sph. or a + sph. required in addition to the − cyl.

The foregoing are typical classes in which the As. is presumed to be manifest. Some cases will be met with where subjective testing does not lend itself so readily, as the descriptive matter reads, to the determination and correction of the optical defect, especially when corrected V. is subnormal or Ac. very active.

When the principal meridians are determined so that the position of the axis of the correcting cyl. is known—this corresponding to the blurred lines of the chart—as a matter of procedure a Cx. cyl. should be first applied; this will make V. worse for the types if, as in most cases, a Cc. cyl. is needed. When the fogging has been properly carried out there can be no doubt that a Cc. cyl. is required and this will, at once, improve sight for the types. After correcting the As. of each eye there remains (*a*) the binocular test with + sph.'s and these if accepted, may change the nomenclature of the class of As., (*b*) the near point test, (*c*) the muscle test, and (*d*) the Pres. test. The general routine tests are as necessary in As., even simple As., as they are in H. or M.

Points on Correcting As.—The As. of an eye being the same for any position of the point of vision, the cyl. selected *for distance* is that which is required for *close work* whether the subject be young or presbyopic; no near tests for As. are needed, nevertheless a presbyope may reject them (vide *Presbyopia*), and the influence of effectivity with strong cyls. must not be forgotten. The consideration of such changes may be of theoretical interest but the cyl. selected for distance may usually be safely given for all purposes.

In theory a full correction of As. is required but, in practice, if sectional Ac. is very active, a satisfactory result is obtained by under-correction. With an old eye there is little difficulty in selecting the cyl. which gives best V. and equality of the astigmatic bars; for a young eye the general rule is that the manifest As. as found when the eye is fogged should be corrected. If, then, any remain masked, it will manifest itself in the course of time. It is, also as a general rule, safer to under-correct at first when the defect is high, the power of the lenses being increased as the wearer becomes used to them.

When low As. causes asthenopia in close work, the use of lenses for distance may be excused until, at least, it be proved that their use in close work only does not cure the asthenopia. With a very high general error and a low degree of As. the latter may often be ignored, especially if the cyl. does not improve V. to an appreciable extent, as for instance, where there is H. or M. over 10 D. and As. of a quarter or half diopter.

A cyl. may markedly improve V. or it may not improve it at all, the latter because the lens merely takes the place of sectional Ac.; when unaided V. is normal it cannot be made better. The cyl. here is needed and this condition must not be confused with that mentioned in the last paragraph. Another cause of failure to improve V. materially, results from subnormal V. A. due to the previous absence of any sharp retinal focus; this is the same as occurs in absolute H. and, like it, the use of corrective lenses should bring about an improvement in the visual acuity.

When Ac. is very active and fluctuating it is as well to give sph. lenses only for temporary use, and especially so if the H. is fairly high compared with the As. and cyls. have not been previously used. When correcting cases of As. it is often advisable not to depend on the results obtained from a single test. A record being made of the first, the second test will be more quickly and accurately made.

In some cases a certain discomfort may be experienced with cyls. when first used; or they may cause obliquity of straight lines or curvature of flat surfaces. If the lenses are correct these symptoms rapidly disappear, they being mental effects due to the changed retinal impressions. Another and more serious cause of distortion is the non-coincidence of the principal Mers. of the eye and lens and may be due to improper location of the cyl. axis or it may be due to the fact that, while the cyl. position is correct, the eye itself is torted owing to insufficiency of the oblique muscles caused by the oblique As. In this case the proper cyls. should remedy the muscular trouble in the same way as + sphs. remedy insufficiency of the external recti by relieving Ac. action.

Although when employing the Orthops chart it is rarely necessary, yet, sometimes, a more exact location of the axis of the cyl. is obtained by rotation either way a few degrees from the originally selected position, especially if the cyl. is of high power. When this adjustment is being made the subject should view the smallest line of types legible and *not the astigmatic chart*, so that he may attain the maximum acuity of vision.

When testing As. it is highly essential that the head be not allowed to rotate over towards the one shoulder; nor inclined in the vertical or horizontal planes, as vision would then be oblique through the lenses. These habits are very common with astigmats who quite unconsciously indulge in them. It is also essential that the trial frame be exactly horizontal.

In no circumstances, with or without any spherical, can any other lines of a fan be the *clearest* or the most *blurred* than those which correspond to the principal meridians of the eye; nor can the *greatest contrast* be secured between the two halves of the diamond in any position other than that which corresponds to the principal meridians of the eye. If the diamond be turned so that the lines be intermediate to the principal meridians, they are equally blurred.

Coloured Fringes.—It sometimes occurs that coloured fringes, due to chromatism of the eye, lie within the macular area so that one or both sets of bars appear to be coloured. This is almost a certain indication of mixed As. either natural or produced artificially by insufficient fogging or by relaxation of the Ac. during the test. In mixed As. we have one focal line in front and one behind the retina so that, in a good many cases, the retina lies approximately in the circle of least confusion and this has oppositely coloured fringes at the extremities of its two diameters which are parallel to the principal meridians of the eye. The bars lying parallel to the principal meridians will therefore be seen coloured blue and red, but the former is much less pronounced as, being comparatively dull, it is more or less lost in the blackness of the bars themselves; the red is, however, generally very pronounced. The colours can be eliminated in the following manner and the correct strength of cyl. arrived at. Weak convex sphericals are put up until the colours disappear and then if the lines that were originally black are again rendered the blacker, the concave cyl. is too weak, but should the originally grey lines appear the sharper, with an added + sph., the concave cyl. is too strong. The trouble experienced with chromatism is only another argument in favour of the fogging system.

The Stenopæic Slit consists of an opaque disc, having a slot-like opening of ·5 to 1 mm. used for determining and correcting As.; the most useful width is ·75 mm. The one eye is occluded, the disc is put in the frame horizontally, before the other, and slowly revolved while the subject regards the types; the slit during rotation must be centred for the visual line. In some certain position he will see better than in any other; this is generally the Mer. of least defect and at right angles to it, is that of greatest error. If there is no As. the V. is equal in all Mers., while if it is much better in one position, there is either simple As. or As. that is high compared with the general error. On the other hand the slit may fail to determine the principal meridians if the As. is of very low degree, especially if the general optical defect is high or Ac. active. Also in mixed As., where the opposite errors are about equal in degree and Ac. passive, the sight is equally blurred for all positions, unless a + or − sph. be used in conjunction with the slit.

The one principal Mer. being located, that strongest + or weakest − sph. is found which, when placed in front of the slit, gives the best visual results; the slit being turned through 90° and a similar procedure followed, the two principal powers have then been approximately determined. The slit is removed, the combination is put up as a sph.-cyl. and the test completed according to ordinary rules. The difference between the two powers is the cylindrical element of the combination, the axis being in the Mer. of least Am. which is corrected by the spherical. As an example, if a + 3 is accepted at 40° and + 5 at 130° the combination needed is + 3 S. ⊂⊃ + 2 Ax. 40°. If the two powers are − 3 at 40° and + 2 at 130°, the combination is − 3 S. ⊂⊃ + 5 C. Ax. 40° or + 2 S. ⊂⊃ − 5 C. Ax. 130°.

The principle involved in the use of the stenopæic is that each principal Mer., independent of the other, is isolated and tested for its spherical error. The stenopæic reduces the size of the effective aperture of the eye, in the meridian at right angles to the slit, so that the focal line pertaining to that meridian is reduced to *practically* a point. Since, however, the stenopæic does not actually reduce that line to a point, vision with the stenopæic is not so good as it is when the eye is corrected by a cyl. or a sph.-cyl.; also with lenses, and without the slit, more light enters the eye.

The stenopæic is useful in special cases, particularly if of high degree, where the ordinary test fails, but is useless if As. is low or completely masked or if Ac. is very active. Sph. lenses and the types are used in conjunction with the stenopæic slit and not cyl. lenses or the As. bars. The smaller the slit, the more effective is the stenopæic up to a certain point but, if very narrow, the quantity of light admitted to the eye, is too much reduced for clear vision; also irregularities of the edge become apparent and diffraction occurs. A slit nearly as wide as the pupil has no stenopæic effect at all.

The Placido Disc or Keratoscope is a disc, having alternate black and white concentric rings whose widths increase from the centre outwards, with about a + 4 D. sph. lens fixed in a small central aperture. The subject being placed with his back to the light an image of the white rings, reflected from the cornea, is viewed through the aperture. The cornea acts as a Cx. mirror and owing to the arrangement of the disc the rings are seen equally spaced but the whole image is smaller as the curvature of the cornea is greater and *vice versa*. Corneal As. is indicated if the rings are seen elliptical, the long axis of the ellipse corresponding to the Mer. of least curvature and the short axis to that of greatest curvature. It requires practice to distinguish very low degrees of corneal As. with the Placido and, although the form of the innermost ring is what is really required, yet that of the second or third ring can be the better seen. The outermost ring often exhibits the irregular appearance normal to all eyes in the zone near to the sclero-corneal margin. The disc is useful for determining the presence and, approximately, the principal Mers. of high regular corneal As. and for detecting irregular As. and conical cornea (*q.v.*), in which the rings are seen distorted. It is a cheap instrument and has, besides a theoretical interest, a decided practical utility.

The Keratometer, fully described elsewhere, is used for measuring corneal As. The results obtained may vary considerably from the total As. of the eye ; also that measured at the surface of the cornea, is numerically different when represented by a cyl. lens placed some 15 mm. in advance, especially if employed in conjunction with a sph. lens. The change in the majority of cases is, however, small enough to be negligible.

Irregular As.—Here the curvature, and therefore the refractive power differs in different parts of the same Mer. so that light from a point is refracted quite irregularly and comes to no definite focus at all. The various forms of irregular As. are referred to in the following paragraphs.

Irregular Corneal As.—True irregular corneal As. is generally the result of wounds or ulcers of the cornea, but it may also be congenital or spontaneously acquired. It can be determined by the Placido disc, when the rings will be seen reflected from the cornea as distorted circles, or by the keratometer the image of whose mires are seen so confused that they cannot be brought into alignment. Markedly different curvatures of the central and peripheral zones of the cornea cause, if symmetrical, strong spherical aberration rather than irregular As. Any curvature of the cornea, other than spherical or toroidal, such as hyperbolic, parabolic, elliptical or conical, would produce a form of irregular As. The peripheral portion of the cornea is normally irregular but since the iris acts as a stop, this need not be considered.

There is no correction, by ordinary methods, of irregular As., although the sight may be considerably improved by sph. or cyl. lenses. It may also be aided by stenopæic spectacles in the form of slits, or very small apertures or partly opaque lenses to utilize only the better portion of the cornea. The only true remedy would consist of a liquid kept in contact with the cornea by means of a spherical shell; irregular corneal As. disappears when the open eye is immersed in water.

Irregular Lenticular As. may be caused by iritic adhesions producing irregularities of the lens capsule. It may also result from inequality of density, and therefore of refractive index, of some of the layers or sectors of the lens, or possibly a deformity of shape, as a whole, may exist congenitally or as the result of a condition such as incipient cataract. The application of lenses is the same as for irregular corneal As. but here, of course, the theoretical liquid lens would not be of any utility. The liquid aqueous is in contact with the front of the crystalline but as the refractive indices of the two media differ, the former only partially remedies any irregularity of curvature of the front surface of the latter.

Other Forms of Irregular As.—Irregular As. may be caused by differences in the refractive indices of the vitreous, possibly due to the presence of sugar, etc.; obliquity of the visual axis to the axis of the optical system produces coma and radial As. which may be considered a form of the irregular variety. Some regard as irregular all forms other than regular As. of the anterior surface of the cornea, but it is more convenient to regard the static and dynamic lenticular forms as regular. The posterior surface of the cornea may be regular or irregular but its influence can be ignored on account of the small difference existing between the refractive indices of the cornea and aqueous.

CHAPTER VIII

ANISOMETROPIA

Derivation.—αν, without, ισο, equal, μετρον, measure, ωψ eye. It is the condition in which the refraction of one eye differs from that of the other.

Illustration of Aniso.—If, in front of a screen and at an equal distance, there are held a + 9 D. and a + 10 D. sph., the latter illustrate a pair of anisometropic eyes. Whether the screen be nearer to or farther from the lenses, there is a constant difference of 1 D. between the powers. The conditions represented are as follows: When the screen is at 9 cm. the eyes are unequally H.; at 10 cm. one Em. and the other H.; at 10·5 cm. the one H. and the other M.; at 11 cm. the one Em. and the other M.; at 12 cm. both are M. but to different degrees. By the addition of cyls. to the sph. lenses further variations can be obtained.

Aniso. Congenital and Acquired.—Any difference between the eyes may be either congenital or acquired, and it is difficult to decide which it is if H. be taken to be the normal condition of an eye at birth, for the difference may have been then present or the one eye may have developed more than the other. Acquired Aniso. may result from extraction or dislocation of the crystalline, or from operation or wound involving the cornea. If one eye is highly H., the Aniso. is probably congenital; if the one is highly M. it is probably acquired; differences in the degree of As. indicate a congenital origin. Some authorities include under Aniso. loss of Ac. in one eye but strictly the latter does not come under this heading at all.

Frequency.—Aniso. is the rule rather than the exception and, in fact, so seldom are the eyes found to be exactly equal that the term anisometropia is frequently used only to denote the condition where the difference is considerable.

Antimetropia is the name sometimes given to the condition where the one eye is H. and the other M., the term *anisometropia* being reserved for where there is, in both eyes, H. or M., but to different extents.

Variation of Degree.—The degree varies from a small difference of, say, ·25 D. in the amount of H., M. or As., to a condition of high antimetropia.

Divisions.—We divide Aniso. into high and low, for the reason that in the former, apart from the actual optical errors, the difference itself requires consideration whereas in the latter, as a rule, no special consideration of the Aniso., as such, is demanded.

Low Aniso. includes differences up to 1 or 2 D.—perhaps more—where the general optical condition is the same in both eyes; cases where there is As. of one eye and not of the other; small differences when both eyes are As., and also all those—and this is the chief point—where correction of the optical differences, *i.e.* equalization of the eyes, does not occasion discomfort or confusion of vision.

High Aniso. includes differences over 2 D.—perhaps less—where both eyes are H. or both M.; high differences in As.; cases of antimetropia and all those where equalization of the refractive condition of the eyes is a source of discomfort or confusion.

Determination of Aniso.—V. may be, and usually is, unequal, different correcting lenses are needed, and the near points are at unequal distances. Equal V. does not, however, prove the absence of Aniso., for the reason that Ac. may be unequally exerted or the defects, although different in nature, may cause equal diminution of V.; nor does unequal V. determine the presence of Aniso. because there may be amblyopia, incipient cataract or other conditions not purely optical.

Vision in Aniso.—The sizes of the two retinal images must, in general, differ in Aniso. Even when V. of both eyes is equal, the nodal points are, owing to unequal Ac., differently placed with respect to their respective retinæ. When V. is not clear in the one eye, the more blurred retinal image is the larger. Nevertheless the brain fuses the two images and both are appreciated because, no matter how blurred the one image may be, or how much larger than the other, binocular is usually better than monocular vision. The actual V. and V. A. of each eye depend on its optical condition.

The P. P. and Amp. of Ac.—If both eyes are equally H. or equally M. or the difference in the refraction is not great, we take it that the accommodative Amp. is the same in both eyes, it being governed chiefly by age. Consequently if both eyes are equally H. or M., the position of the P. P. must be the same for both, with or without correcting lenses. If the eyes are unequally H. or M. the P. P.'s must differ without lenses, but they must be equally distant when the Aniso. is corrected—that is, when the excess of refraction of the one eye over the other is neutralized.

Ac. in Aniso.—If unaided V. is equally clear in both eyes it is generally because the Ac. is unequally exerted, but this is only possible to a small extent; where the difference is great it is impossible for the one eye to accommodate so much more than the other, and the influence of Con. in this connection would make it difficult if not impossible. Equal Ac. with consequent blurring of the one image and partial disuse of the one eye, is in old people the usual condition with Aniso., whether low or high; it is also equal, at all ages, with high differences, except where V. alternates.

Asth. in Aniso.—Asthenopia is almost a certain accompaniment of unequal exertion or effort of Ac. It is possible that by training or otherwise unequal accommodative actions may result from equal efforts, and some young people seem to obtain binocular clear vision without Asth., but later in life there is either discomfort or vision is not simultaneously clear. When Asth. (*q.v.*) is present, it may result from various conditions, but if due to Aniso., equalization of the refraction of the eyes will cure it; unequal corrections of equal eyes may cause it.

The Correction of Aniso. consists of lenses that equalize the refractive powers so that Ac. is equally exerted for all distances. Full correction of the Aniso. is usually accepted in low, but not in high degrees; it is the rejection of full correction which causes the division, rather than any numerical expression of the Aniso.

Suppose a case apparently requiring O. D. + 1 D., O. S. + 2 D., these being the strongest lenses accepted for the manifest H. and there being an equal amount of uncorrected latent H. remaining in each eye; the P. P. will then be at the same distance for both eyes. It does not, however, always occur that the Ac. exerted, when the one and the other eye is being tested, is that which leaves an equal degree of latent H. in both eyes; it may even happen that a myopic case is unequally corrected owing to active Ac. Consequently it may be laid down, as a general rule, that *when the eyes are equalized the P. P. of each is at the same distance, and that when they are not equalized, the near points do not correspond.* Therefore in order to decide that the refractions are equalized, the P. P. of each eye, with correcting lenses found monocularly, must be taken and if the one is found more distant than the other, the distance tests are most likely faulty and must be revised.

Taking the above example of O. D. H. 1 D. and O. S. H. 2 D. the P. P. of each would be, say, 10 D. at 20 years of age. Should the left eye show only 9 D., there is obviously 1 D. more uncorrected H. than in the right. A revision of the original test would probably result in the acceptance, by each eye, of such lenses as make the near points equal. Generally this is successful although occasional inequality in the near points without any discomfort is found for no apparent reason; such cases are rare, but, as an exception, one eye may have Em. and the other H. partially latent.

The Correction of Low Aniso. consists of determining the refractive error of each eye independently and confirming it by the position of the near points. This being done, all treatment is as given for H., M., As. and Pres. Perfect equalization is generally tolerated.

The Correction of High Aniso. presents many difficulties and perfect equalization is, at first, seldom or never tolerated. A common classification of high Aniso. is as follows: (*a*) Where one eye only is used in vision. (*b*) Where each eye is alternately used. (*c*) Where both eyes are simultaneously used.

Aniso. with Monocular V.—In this condition the one eye has very defective sight, which may be congenital, or due to accident, disease or non-use; the latter is the most common cause especially if there is also strabismus. The useful eye is tested and given the lens or combination which best suits it and, in order to balance the frame and for the sake of symmetry of appearance, a similar lens is given to the non-seeing eye. The worse eye, although permanently excluded from use when the better one is engaged should, if not completely amblyopic, be prevented if possible from becoming still more defective by being given visual exercise when fitted with the best possible optical correction. It is thus kept available in case of some unfortunate accident to the better eye. When both eyes are H. or M. to different extents, the one frequently deviates into a monolateral squint (vide *Strabismus*), the eye of less defect being exclusively used for all distances. Very low Aniso. may cause a monolateral instead of an alternating squint, which would rather be the case if the eyes were equal.

Antimetropia with Real Alternating Binocular Vision.—In this condition, both eyes are used but not simultaneously. The more usual class is where the one eye is myopic and used for near work, while the other is emmetropic or hypermetropic and used for distance. There may be a more or less noticeable alternating squint for any distance. Notwithstanding correction it is often impossible to obtain simultaneous vision, the *fusion sense* apparently being absent from congenital or acquired causes. That the one eye is M. and the other H. favours the condition of alternating vision since the one is adapted for distance and the other for near vision; and it is difficult to decide whether the alternating V. results from the antimetropia, or whether the latter is the result of a congenital inability to use the two eyes simultaneously in binocular vision. As a rule a person is not cognizant of the fact that he is using only the one eye and frequently—when vision is made equally good in both—he does not know which eye he is using at any particular moment. There is complete and unconscious suppression of the one image and no inconvenience is felt.

Even if simultaneous vision be elicited, it is generally so confused and uncomfortable that it has to be relinquished. In such a case, or if simultaneous vision cannot be elicited at all, it is necessary to correct each eye, on general principles, for the work it does. That is, the H. eye is given best possible vision for distance and the myopic eye corrected for the best distance for near work. If vision is confused after correction of each eye separately, the sense of simultaneous vision exists and, generally, if it is not confused, such sense does not exist. This point ought, however, to be decided by one of the special methods described elsewhere.

When simultaneous vision is not produced and each eye is corrected for its own special distance, the lenses can be mounted in a single frame as would be done if comfortable simultaneous vision were obtained. If, however, simultaneous vision is intolerably confused, the lenses must be mounted in separate frames, the one for distance and the other for near work. The eye in use is given its correcting lens and the other put out of action by a plano or a lens through which that eye cannot distinctly see.

The Treatment of High Aniso.—Each eye is corrected on general principles—that is, the near points are measured and the eyes equalized as much as possible. If, when both eyes are engaged in vision, the lenses are comfortable and there is simultaneous binocular vision, the corrections thus found are prescribed. If these lenses cause uncomfortable vision, its source must be sought, and the remedies suggested in the next article applied. These consist mainly of modifications of the corrections in the direction of giving partial correction only to the more ametropic eye.

Troubles Arising from Correction and their Remedies.—(*a*) Confusion owing to the size of the two images and want of Ac. in the one eye when there is monocular aphakia (*q.v.*).

(*b*) Diplopia when there is concomitant strabismus (*q.v.*).

(*c*) Distortion caused by strong oblique cylindricals (vide *Astigmatism*).

(*d*) Non-fusion owing to difference of size of images, or distance of projection in space.

The remedies are (1) to decrease the difference between the lenses and (2) to place them in the anterior focal planes of the eyes.

(*e*) Asthenopia or diplopia caused, on rotation of the eyes, by prismatic action when the lenses differ greatly in strength (vide *Prisms* and *Prismo-sphericals*).

The remedies are (1) instructions to turn the head rather than the eyes for side vision, (2) partial correction only of the worse eye, (3) adjustment of the frame for the working distance so that the eyes look through the optical centres of the lenses, (4) the use of the new system bifocal lens by the more defective eye. In this the central power of the lens is that required by the worse eye, and the peripheral power equal to that required by the better eye.

(*f*) Asthenopia, or confusion of sight, from unequal accommodative action.

The remedy is to increase the power of the one lens or reduce that of the other.

Troubles arising from unequal corrections are, obviously, likely to be removed by lessening the difference. This is brought about by reducing the strength of the stronger lens when both are Cx. or both Cc., or reducing both of them when they are of opposite nature. If the one lens is + 2 and the other + 6, the difference is 4 D.; reducing the stronger to + 4 makes the difference only 2 D. If the one lens is + 2 and the other − 6, the difference is 8 D., which would be reduced to 6 D. by making each 1 D. weaker. Whether one or both are altered depends on various circumstances. Thus suppose the lenses are O. D. + 2 D. and O. S. − 3 D.; we could reduce or increase the Ac. action in O. D. by respectively increasing or reducing the + lens ; with O. S. it is inadvisable to increase Ac. by giving a stronger Cc. but we could reduce it by giving a weaker one. If O. D. is + 2 and O. S. + 6, we could not well lessen the difference by increasing the + 2, so that partial correction of the higher error, by reducing the + 6, is the only remedy if there is discomfort with full correction.

Points on Treating Aniso.—The conditions vary so much that each case may be said to be characteristic of itself only. It is therefore impossible to make definite rules for the treatment of Aniso. but the lines, as already indicated to be followed, may be epitomized as follows :

First consideration must be given to the better eye, for it is preferable to obtain useful and comfortable sight of one eye than bad and painful sight of the two.

The difficulty does not lie so much in deciding on the correction for the better eye, but on what should be given to the worse eye. The better eye is corrected and the other, subordinate to the first, is brought up to its standard as nearly as can be tolerated.

The retinal images should be made as nearly equal as is possible; this depends largely on the position of the lenses.

The near points should be equalized as nearly as possible and thereby the accommodative actions also. If in doubt as to the eyes being equal make them artificially M. 4 or 5 D., and measure the P. R. of each.

Although equalization of small differences is usually tolerated and not so with high differences, there is no sharp line of demarcation. If full correction of the worse eye is not, at once, accepted, it may be later on after partial correction has been used. The eyes should be kept under observation and tested every few months for a time.

A partial correction is always better than none at all, for with it the general conditions of sight are improved.

Young people, having greater adaptability, accept full equalization more readily than old ones.

When simultaneous binocular vision is impossible, each eye must be suited for the work for which it is adapted.

Discomfort caused by cylindricals, as a rule, disappears more rapidly than that caused by unequal sphericals. Generally, reduction of the sphericals only is required in order to produce comfort, but sometimes that of the cylindricals is also necessary. Prisms should be used only as a last resource.

The use of lenses improves reduced acuity caused by non-use of an eye Therefore when both eyes do not use full correction, the worse eye should be exercised by itself. This exercise can take the form of simply looking at distant objects daily when the better eye is occluded but, more effectively, it is done by reading print as small as possible, using for the purpose full correction for that eye in a frame provided with an opaque glass for the better one (vide *Ocular Exercises*).

In compound As. sometimes better results are obtained if the sphericals only are used for two or three weeks.

In complicated cases the suggested correction should be tried by the customer in the test room for reading, walking about, looking out of window, etc., in order to ascertain whether it is likely to be tolerated with a reasonable degree of comfort.

CHAPTER IX

ORTHOPHORIA, HETEROPHORIA AND STRABISMUS

Orthophoria

ORTHOPHORIA.—(ορθος, correct; φορος, tending) is the condition in which, the motor muscles being at rest and the eyes in their primary position, the visual axes are parallel to each other. The state of normal muscular balance, not only when the eyes are in ordinary use, but also when they are subjected to a balance test is termed *orthophoria.* Any departure from parallelism of the visual axes, when the muscles are at rest, is termed *heterophoria* (*q.v.*).

Fusion is the sense of simultaneous single binocular vision. It occurs when the eyes fix the same object and the two ocular images, falling on corresponding parts of the retinæ, are combined, by the mind, into a single impression.

Prisms.—When a prism is placed in front of an eye the latter turns towards the edge so that the macula may receive the light refracted towards the prism's base; otherwise double vision must ensue. The same results if a prism be placed in front of each eye, but the effect of a single prism is shared equally by the eyes; thus, if a 2°d prism base out be placed in front of the right eye both converge 1° the same as if a 1°d prism were placed base out in front of each eye. In all muscle tests a single prism is employed, its effect being binocular.

Nomenclature of Muscle Action.—*Adduction* is convergence or turning the eye inwards while *abduction* is divergence or turning the eye outwards. *Superduction* is an upward and *subduction* a downward movement of the eye.

Nomenclature of Ophthalmic Prisms.—An *adducting*, or minus prism, is one base out; it causes or increases convergence in the same way as a − lens causes or increases Ac. An *abducting*, or plus prism, is one base in and causes divergence or lessens convergence in the same way as a + lens lessens Ac. A *superducting* prism is one base down; a *subducting* prism is one base up. A *horizontal* prism is one with its base apex line horizontal, the base being in or out. A *vertical* prism has its base apex line vertical, the base being up or down.

A *relieving* prism has its base towards an inefficient muscle. Thus a + prism relieves the internal, a –. prism the external recti. An *adverse* prism is one having its base towards the antagonist of a weak muscle, causing increased action of the latter. A *combining* or *measuring* prism causes the two images, seen in a muscle test, to be projected to the same position in space.

Position of the Two Prisms.—Prisms may be needed :—Both base in or both base out ; the one base up, the other down ; the one base in and up, the other in and down ; or the one base out and up, the other out and down. In all cases the base-apex lines are *parallel* and the two prisms in *opposition*, so that, if the two were placed one over the other, they would neutralize.

The Strength of the Muscles, which are yoked in order to maintain single vision *on the median line* in the vertical and horizontal planes, can be measured by the power of the strongest prism they can overcome, *i.e.* see through without diplopia ; the test object being, say, a candle flame at 6 m. distance. The average power demonstrated is as follows :—

The external recti, 4^{Δ} to 8^{Δ} base in ; the internal recti, 20^{Δ} to 30^{Δ} base out. The superior and inferior recti, 2^{Δ} to 4^{Δ} base up or down.

In general, *insufficiency* of the *external* recti is indicated if *less* than $+ 4^{\Delta}$ or $+ 8^{\Delta}$ and, of the internal recti, if more than $+ 4^{\Delta}$ or $+ 8^{\Delta}$ is overcome ; this test is not, however, very definite. It should be noted that the power overcome by the external recti indicates the relative negative convergence, and that overcome by the internal recti the relative positive convergence. The difference between them (25^{Δ} to 40^{Δ}) is the amplitude of Con., relative to Ac. = 0. If Ac. be stimulated, the internal recti have normally a much greater action.

Muscular Imbalance.—It is not easy, nor is it essential—with certain exceptions given later—to distinguish between the deviation of the one visual axis from its fellow and the deviation of both from each other ; *i.e.* it is not of material importance whether the one internal rectus is relatively weaker than it should be or whether both internal recti are relatively weaker to half the extent. We can then classify muscular imbalance as (*a*) relatively strong adduction, (*b*) relatively weak adduction, (*c*) relatively weak superduction of the one eye *or* subduction of the other. Of these, (*a*) and (*b*) are horizontal and (*c*) is a vertical imbalance. The term *muscular imbalance* is used in a general sense ; it can be divided into two main classes, viz. (*a*) heterophoria or muscular insufficiency, sometimes called latent strabismus and (*b*) strabismus or squint.

Causes of Muscular Imbalance.—(*a*) The cause may be *anatomical* owing to (1) a faulty attachment of a muscle which may be too far back, too far forward, or incorrectly oblique. (2) A muscle being abnormally long or short, small or large (deficiency or excess of fibres) or deficient in contractility or elasticity. (3) Abnormal location of the macula.

All the above may pertain to both eyes, also (1) and (2) to more than one muscle.

(*b*) The cause may be *physiological* or *pathological*, there being (1) deficiency of nerve force or paresis. (2) Spasm of a muscle. (3) Excessive or deficient innervation of some muscles, or excessive or deficient resistance of opposing muscles.

(*c*) The third cause, which indeed might be included in (*b*), is the result of refractive error, but, of course, this cannot apply to vertical imbalance.

The above causes may be considered generally. Should the external recti (or the one rectus only) be anatomically inferior to the internal, then the latter are actually stronger than the external and the eyes tend to turn inwards; the same tendency would be present if there were spasm or excessive innervation of the internal recti, or paresis or deficient innervation of the external recti. Similarly the internal recti may be actually weaker than the external, or there may be spasm or excessive innervation of the external, or paresis or deficient innervation of the internal. In either case the eyes tend to turn outwards. Thus the cause of imbalance or deviation from parallelism may be active or passive; it is active if some muscles are too strong, receive too much innervation, or suffer from spasm; it is passive if the antagonistic muscles are too weak, receive too little innervation, or suffer from paresis. So we may have departure from parallelism, in the direction of convergence, not only from defects of the internal, but also of the external recti; in the same way divergence may result from defects of the external, as well as from those of the internal recti. Whatever the anatomical or physiological reason for imbalance, the result is a want of equality between opposing muscles, so that some overcome, or tend to overcome, their antagonists; they are therefore *relatively* stronger, or the antagonists are *relatively* weaker, and, in this sense, the term *strong*, or *weak* muscles, will be employed.

The strength of the internal, as shown by their ability to overcome prisms, is normally far greater than that of the external recti, yet when the muscles are at rest the eyes usually diverge. This would seem to indicate that, anatomically, the external are the relatively stronger pair and that, physiologically, the internal are so. In other words, the internal recti are susceptible to innervation to a far greater extent than the external and this is perfectly natural since convergence is a normal function constantly in action while divergence is never required for binocular vision. The function of the yoked external recti seems to be that of restraint or regulation exercised over the yoked internal recti when convergence takes place.

With respect to refractive errors, as a cause for imbalance of the horizontal muscles, we know that H. causes esophoria and convergent squint, and that M. causes exophoria and divergent squint, the immediate cause being usually assigned, respectively, to excessive or deficient innervation of the internal recti. There is probably no actual weakness of the horizontal muscles in these cases because no difficulty is found in turning the eyes to the right or left, but since the correcting lenses do not immediately cure a heterophoria, there are probably other factors involved. Refractive Eso. and Exo. are functional disorders, there being, in the first, difficulty with the external, and in the second with the internal recti, in maintaining binocular fixation. In this sense we may regard them as weakness of the one or other pair when yoked together in action, such functional weakness not obtaining when one internal and one external rectus are yoked for lateral rotation to the right or left; Eso. and Exo. are terms applied to the two eyes jointly, and not to a single eye. The insufficiency does not, however, immediately disappear on application of the correcting lenses because the defect has become more or less chronic and therefore does not at once respond to the removal of the cause. In other words, we do not generally find any marked alteration in the imbalance for distance when the correcting lenses are applied and this especially in M. as no change in accommodative action takes place for distance. In H. we may find a slight diminution of the Eso. on relieving the Ac. and it is probable that continued use of the correcting lenses may ultimately remove the insufficiency altogether. Again, refractive insufficiency is due mainly to close work with uncorrected Am. and it is, therefore, at the reading distance that we should find the greatest immediate reduction in the horizontal imbalance on application of the full distance lenses. Thus Eso. and Exo. may be regarded as conditions in which the two external or the two internal recti are *relatively* weaker than their antagonists, that is, as conditions in which there is insufficiency of the one or other pair.

Anatomical or physiological imbalance may be augmented or counteracted partially or completely by the "refractive" imbalance, or the latter may predominate over an original defect. We expect to find Eso. in H. and Exo. in M. and if we find the reverse, we may draw the deduction that, were it not for the refractive condition, the apparent degree of imbalance would be higher. Squint, in many cases, would probably not be present unless there were actual, as well as functional, weakness of muscles.

Heterophoria.

Derivation (ετερος, different; φορος, tending).—Heterophoria is the condition of muscular imbalance where perfect fusion is maintained only at the expense of extra effort on the part of the relatively weak muscles. Only under certain tests, in which fusion is made impossible, does actual deviation of the eyes occur. Also it is manifested occasionally when vision is dulled, *e.g.*, when one is sleepy or abstracted, the muscles being then not under control. Similar condition occur when one is drunk, or when the muscles are extra fatigued as after a continued spell of close work. In these circumstances vision becomes "double," the eyes taking up their position of rest in which the visual axes are no longer parallel or directed to the same object. It is to heterophoria that the term *muscular imbalance* is usually applied, although the latter, since it includes squint, has a wider meaning.

The abbreviations Ortho., Hetero., Eso., Exo., Hyper., Hypo., Ana., Kata., and Cyclo. will be used in this chapter to denote the conditions referred to in the next article.

Classes.—(*a*) Esophoria or Eso. is insufficiency of the external recti. The eyes tend to turn inwards owing to the internal recti being *relatively* stronger than the external.

(*b*) Exophoria or Exo. is insufficiency of the internal recti. The eyes tend to turn outwards owing to the external recti being *relatively* stronger than the internal.

(*c*) Hyperphoria or Hyper. is insufficiency of the one inferior rectus. The eye tends to turn upwards. Hypophoria or Hypo. is insufficiency of the one superior rectus. The eye tends to turn downwards. These two conditions can be taken as one, since right Hyper. is the same as left Hypo. and *vice versa.*

(*d*) Cyclophoria or Cyclo. is insufficiency of the oblique muscles.

(*e*) Anaphoria or Ana. is insufficiency of both inferior recti. This term has sometimes been applied to Hyper.

(*f*) Kataphoria or Kata. is insufficiency of both superior recti. This name has sometimes been applied to Hypo.

There are also compound defects as Hyper- or Hypo-Esophoria or Exophoria; or with Eso. or Exo. there may be also Ana. and Kata.; Cyclo. may be associated with any of the other muscular defects. It will be observed that for the condition of heterophoria to obtain there must be *fusion* and relatively weak muscles. If binocular vision is not present there cannot be heterophoria, although there might be orthophoria, because imbalance, unaccompanied by binocular vision, is generally associated with a squint. Consequently we cannot talk of heterophoria of one eye; the defect is, and must be, common to the two eyes.

Prevalence.—Hetero. is as common as ametropia. Absolutely perfect muscular balance is uncommon—indeed a degree of divergence not exceeding 1 M. A. when the eyes are at rest, is considered to be practically the normal condition.

Symptoms.—Small, and even high degrees, very frequently give rise to no discomfort at all, but Hyper. and Hypo. are more likely to be troublesome than Eso. and Exo., and further the former cannot be aided by lenses whereas the latter can. Frequently Hetero. does not manifest itself until 20 or 30 years of age or later, and this apart from the influence of any error of refraction; it is the case with Hyper. especially. Symptoms of Eso. and Exo. are, in general, the same as those of the refractive errors; the two are so connected with, and dependent on, each other that they cannot easily be dissociated. These common symptoms are discomfort, asthenopia, headache and neuralgia; dizziness and vertigo; pain in, or at back of eyes; lachrymation, photophobia and intolerance of wind. If these symptoms are present in Em., or very low Am., or if they continue after correction of the Am., they can, more exactly, be attributed to the Hetero. and not to the Am., if there be any.

Special symptoms of Hetero. are occasional diplopia; closing one eye; pain at temples, indicating Eso.; pain between the brows, indicating Exo.; pain over the one brow only, or more over the one, indicating Hyper.; abnormal position or inclination of the head, with or without lenses; wearing glasses with the one lens higher than the other, or both lenses high or low with respect to the visual axes, or with the frame so bent that the lenses are out of adjustment in any way.

Testing Hetero.—The power of the lenses given to correct errors of refraction depends on the condition of the horizontal muscular balance and no optical test can be considered complete until the latter has been learnt. Further, should asthenopia continue after correction of the refractive error, its cause must be sought for in the muscular condition. As a rule only a distant test is required, but if the actual use of prisms seems to be indicated, the tests must be made not only at 5 or 6 m. but also at the reading distance; this is requisite for both vertical and horizontal insufficiencies. With respect to the horizontal muscles, at the greater distance we test excess or deficiency of initial Con. while at the reading distance we test the initial plus the accommodative Con.; the two, frequently, do not correspond.

All tests for Hetero. are based on the temporary destruction of fusion. When this occurs, the relatively stronger muscles turn the eyes so that the latter take up their position of rest. The one eye then fixes the object and the *front* of the other eye deviates—except in cyclophoria—in the direction of its stronger muscle, the back rotating in the opposite direction. The image in the deviating eye—the false image—is then not macular, so that the projected images of the two eyes do not correspond in space. If the retinal image lies on the nasal side of the macula, it is projected to the temporal side of the field and *vice versa*, so that the projection of the false image is towards the relatively weaker muscle of the deviating eye and its angular displacement is equal to the total deviation between the visual axes. In Hyper. the image is above the macula, and projected downwards.

To illustrate this, let us suppose that the object viewed is a flame at 6 m. distance and that before the right eye there is placed a Maddox rod (*q.v.*) axis horizontal, which converts its image into a vertical streak of light. Then the left eye sees a flame and the right eye a vertical streak of light.

Let us further suppose that both eyes tend to deviate outwards 1° so that, in the position of rest, there is a total angular deviation of 2° between the visual axes. If the right eye be occluded, the left eye projects its *flame* image on to the object and the right deviates 2° outwards. If the left eye be occluded the right eye projects its *streak* image on to the object and the left eye deviates 2° outwards. If both eyes are uncovered the left eye fixes the flame, the right eye deviates outwards 2°, and the streak is seen separated from the flame by a distance equal to tan. 2° on a radius of 6 m. or approximately 21 cm.; it is crossed over towards the left, *i.e.* towards the deficient internal rectus. If the left eye saw the streak and the right eye the flame, the streak would be similarly crossed—to the right—or towards the weaker internal rectus of the left eye. The streak generally wanders about for a few moments at the commencement of the test, but finally settles down to a fixed position indicating the degree of heterophoria. To combine the images or, in this case, to make the streak cut the flame, there is needed a + 2°d prism placed in front of the right or left eye indifferently, or a pair of 1°d prisms base in.

Since, as before stated, Hetero. is common to the two eyes, it does not matter before which eye the testing apparatus is placed; the same degree of defect would be disclosed in either case. When, however, one eye sees better than the other the testing disc, such as the Maddox rod, should be placed before the better eye.

To avoid constant repetition in the description of the following tests it should be noted that—

1. The confusion or testing disc, or doubling prism, is placed before the *right* eye.
2. The muscle test is made after any refractive error is corrected, and with the correcting lenses before that eye which sees the test object, or before both eyes if the images are similar, as with the double prism.
3. The false image seen by the deviating eye is towards the weak muscle.
4. The combining or measuring prism is placed in front of the deviating eye with its base over the weaker muscle (*i.e.* towards the false image); or it is placed in front of the other eye with its base over the corresponding muscle.
5. The deviating eye is rotated in the direction opposite to the image it sees.
6. The measured deviation is the total between the eyes.
7. When treating of horizontal imbalances, the vertical balance is presumed to be normal and *vice versa*.

The Maddox Groove.—This device, the invention of Dr. Ernest E. Maddox, is without doubt the quickest, easiest and best of all muscle tests and rarely is any other needed. The groove consists of a single extremely high-power concave cylindrical ground on a piece of red glass or, better, a series of cylindricals arranged parallel to each other (Fig. 44) termed a *multiple groove.* When light from a small source such as a candle flame passes through a very strong Cc. cyl. it is strongly refracted across the axis, and, to an eye behind the cyl., the flame appears drawn out into a streak of light across the axis. With the multiple groove the various streaks unite to form a long well-defined band of light.

The Maddox Rod is a single highly curved convex cylindrical and the multiple rod is a series of such cylindricals. Its effect and application is the same as the groove but it is not so convenient as it is thicker and the rods are apt to become loose.

The Muscle Chart.—In conjunction with the groove or rod, a muscle scale (Fig. 41) is employed. As shown in the diagram, it simply consists of a series of numbers on each side of a central pointer, those on the left being red and those on the right green. The space between the centre of each number is as many centimetres as there are metres in the distance at which the chart is used, so that for use at 5 m., the spacing is then 5 cm. The divisions represent deviation in prism diopters, which notation is more convenient than the M. A.

The Groove Test.—For the horizontal muscles, the groove is placed horizontal; the vertical streak, seen by the right eye, then (*a*) cuts the flame in Ortho., (*b*) is to the right of the flame in Eso.—homonymous or uncrossed diplopia, (*c*) is to the left of the flame in Exo.—heteronymous or crossed diplopia.

The measure of the insufficiency in △ is indicated by the number on the muscle chart through which the streak passes, or it may be measured by the weakest − prism in (*b*), and by the weakest + prism in (*c*) that causes the streak to cut the flame. The chart and its numbers are, of course, seen by the eye before which the groove is not placed, in this case the left eye. If the fusion sense exists both streak and flame are seen, but sometimes there is at first some difficulty with this. It may be necessary to lessen the brilliancy of the flame by placing a coloured glass in front of the left eye. Non-perception of the streak may also be caused by incorrect centring of the groove before the eye. Sometimes the streak is deviated to so great an extent that *it is off and considerably away from the chart;* in these circumstances a prism must be used to bring the streak back to the chart. Before using the *combining* prism the streak should be allowed to settle down in one place.

For the vertical muscles, the groove is placed vertical; then the horizontal streak seen by the right eye (*d*) cuts the flame in Ortho., (*e*) is below the flame in right Hyper., (*f*) is above the flame in left Hyper.

Usually there is no vertical scale, and the degree of vertical insufficiency is indicated by the weakest combining prism placed before the right eye base down in (*e*) and base up in (*f*). Care should be taken that the groove or rod is exactly horizontal or vertical as needed.

The Vertical Prism Test.—For the horizontal muscles a prism of 4 △ or, if necessary, 5 △ or 6 △ is placed base down before the right eye; this causes vertical diplopia so that two muscle charts at 5 or 6 m. are seen, the one above the other; the upper pertaining to the right and the lower to the left eye. The vertical separation of the two images of the chart should not be too great, but they must be clear of each other, say by an inch or two. Then (*a*) in Ortho. the pointer of the upper chart lies in the same vertical plane as that of the lower. (*b*) In Eso. the upper pointer indicates some number on the right of the lower chart; diplopia is uncrossed or homonymous. (*c*) In Exo. the upper pointer indicates some number to the left of the lower scale; the diplopia is crossed or heteronymous.

If preferred a flame can be used as the indicator in place of the pointer of the chart. Care must be taken that the base apex line of the testing prism is exactly vertical, otherwise a false horizontal deviation is introduced by its obliquity. As with the groove test the two images do not immediately settle into their relative positions, but wander to and fro; the combining prism is that which brings the two images into the same vertical plane. For the vertical muscles the chart is placed vertical. A + prism of about 10 △ or 12 △ is employed and, since the external recti cannot overcome it, a horizontal diplopia is produced. The vertical insufficiency is indicated by the right pointer being below the left (right Hyper.) or above (left Hyper.). The combining prism is that which brings both pointers or flames into the same horizontal plane.

The vertical prism test is clumsy compared with the groove test, but in the absence of a Maddox groove or rod it is fairly efficient. The two images being similar there is, however, always a tendency on the part of the muscles to attempt fusion, whereas this is not the case when the two images are very dissimilar, as in the groove test.

The Double Prism Test.—The apparatus consists of two prisms of about 5 △ each, joined base to base (Fig. 45) and the disc on which they are worked is placed before the right eye so that the common base line exactly bisects the pupil horizontally. The object viewed is a light or globe of which two images are seen separated vertically by the right eye, the left being occluded. When the two images are seen by the right eye in an exactly vertical plane, the left eye, before which a red glass is placed, is uncovered and sees a third (red) flame between the other two. We then have that (*a*) In horizontal Ortho. the central red flame is in the same vertical plane as the other images. (*b*) In Eso. it is to the left of the others. (*c*) In Exo. it is to the right. (*d*) If the central image is midway between the upper and lower images there is vertical Ortho. (*e*) If nearer to the upper flame there is right Hyper. (*f*) If nearer to the lower flame there is left Hyper. The strength of the combining prism is found as in the other tests.

The horizontal and vertical muscles are tested simultaneously by the double prism, but the test is not so good as that of the groove. If there is high vertical insufficiency the central image may be fused with one of the others, and the test is then useless unless the vertical insufficiency be corrected by a prism, when the horizontal test will hold good. As with the single vertical prism, the similarity of the images mitigates somewhat against the efficiency of the test. The appearance of the three images is shown in the following figures :

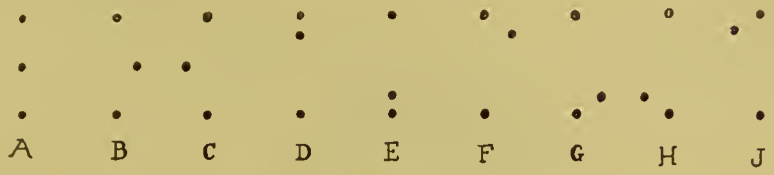


Fig. 57.

A, Ortho. ; *B*, exo. ; *C*, eso. ; *D*, right hyper. ; *E*, left hyper. ; *F*, right hyper-exophoria ; *G*, left hyper-exophoria ; *H*, left hyper-esophoria ; *J*, right hyper-esophoria.

The Cone Test.—The disc is a cone of red glass having a cross cut in its centre so that, when placed vertically in front of the right eye, there is seen a circle of light with a central cross. In Ortho. the centre of the cross lies in the middle of the flame seen by the left eye. In other conditions it is deviated, the vertical limb of the cross indicating the horizontal, and the horizontal limb the vertical insufficiency. Should both conditions exist, an oblique resultant prism can be found which brings the centre of the cross to the centre of the light.

Fig. 58.—The Phorometer.

The floor-stand is not shown.

The Phorometer and Rotary Prism.—The principle involved in these appliances is, that two similar prisms in opposition have no prismatic effect and that when revolved in opposite directions their combined resultant power varies. Similarly a single prism revolved in front of the eye has a varying effect in the vertical and horizontal meridians. The usual form of phorometer, and that to which the name is generally applied, consists of a 5° prism before each eye arranged as to revolve in opposite directions.

When the one is base up and the other base down a vertical diplopia is produced and the degree of horizontal imbalance is indicated on the scale of the instrument when, by revolving the prisms, the two images are brought into the same vertical plane. If the base apex lines are horizontal, the bases being *in*, a horizontal diplopia is produced and any vertical imbalance is indicated by the amount of rotation of the prisms necessary to bring the two images into the same horizontal plane.

The phorometer is extremely ingenious and serves, at the same time, as a means of causing dissociation of the images and of measuring the muscular imbalance. There are separate pointers and scales for the vertical and horizontal defects.

Fig. 59.—The Rotary Prism (Raphael's).

The rotary prism can be used for the purpose of measuring the strength of the muscles instead of employing a series of prisms of varying strength.

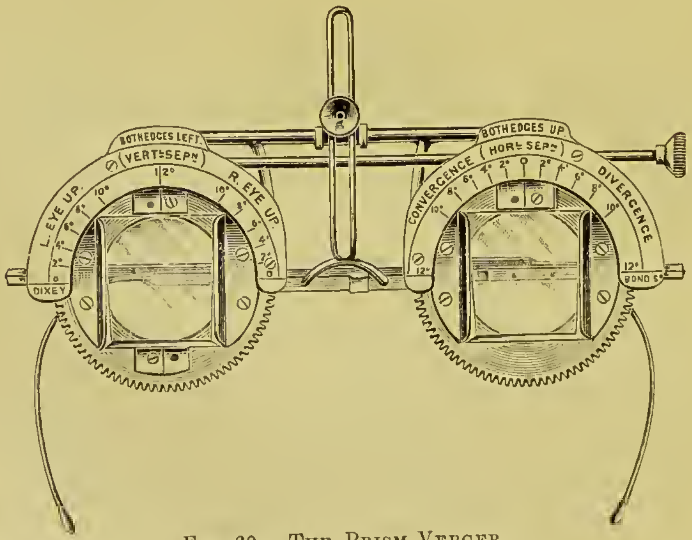


Fig. 60.—The Prism-Verger.

The prism-verger of Dr. Maddox consists of two prisms of 6°d mounted in a trial frame; they are placed both base down and then rotated in opposite directions so that a gradually increasing + or − prism effect is produced.

For the vertical muscles the initial position is, for both prisms, base to the left; then on rotation a gradually increasing vertical effect is introduced.

Other Tests.—In very high degrees of muscular insufficiency diplopia may be produced by placing a red glass in front of one eye and a green glass before the other. If diplopia cannot be elicited by one test another should be tried.

Tests for Near Distances.—That usually employed is the single prism with a test object consisting of a small muscle chart designed as for distance with the spacing proportionally reduced. Even better is the line and dot, as shown in the diagram, which consists of a thin black line about 6 inches in length in the middle of which is a circular dot. With the line held vertically at the reading distance, a prism of about 12△ is placed base down in front of the right eye when (*a*) in horizontal Ortho. one line with two dots is seen. (*b*) In Eso. two lines and two dots, the upper dot being to the right. (*c*) In Exo. the same occurs, but the upper dot is to the left.

For testing the vertical muscles a + prism of about 10△ or 12△ is used and the test chart is placed horizontally. Then (*d*) if there is a continuous line with two dots there is no vertical insufficiency. In Hyper. the line is not continuous and (*e*) in left Hyper. the right dot is the higher. (*f*) In right Hyper. the right dot is the lower.

Fig. 61.

The combining or measuring prism is found as for distance, it being the weakest that brings the dots into the same plane.

The Maddox rod or groove can also be used for taking the imbalance at the reading distance. The general principles are as for distance, but the scale must be reduced in proportion so that, to indicate prism diopters at 40 cms., the spaces between the numbers would be 4 mm. In the centre of the scale, corresponding to the lamp, is placed a small polished button or bicycle ball so that, with a fairly powerful source behind the subject's head, a light sufficiently bright to produce a streak is reflected from it.

Ortho. and Em.—If the eyes are Em. and Ortho., there is exerted for, say, 33 cm. 3 D. Ac. and 3 M. A. Con. For all distances there is harmony in quantity as well as in effort between the two functions, and at all ages until Pres. appears.

Ortho. and H.—Here clear binocular vision calls for Ac. in excess of Con. at all distances; there is, therefore, lack of harmony between the two so far as quantity is concerned. The accommodative action in H. is easy and, by training, the hypermetrope acquires the faculty of producing more Ac. than Con. when the efforts of the two are equal so that no discomfort arises. If the H. requires correction, it should not be too full in order not to reduce the accommodative effort below that of Con. If the faculty of accommodating in excess of Con. be not acquired without discomfort, the condition resembles Eso. and H. (*q.v.*).

Ortho. and M.—For distances where clear binocular vision is possible, Con. exceeds Ac. in quantity but the myope is trained to produce little or no Ac. when the effort equals that of Con. at the ordinary distance of near work. If correction be needed for the M. it should be somewhat less than full for constant wear in order not to render accommodative effort greater than that of Con. If the faculty of converging in excess of Ac. be not acquired without discomfort, the condition resembles Exo. and M. (*q.v.*).

Eso. and Em.—Here Con. is easy and calls for little effort and if the muscles are at rest there is slight convergent strabismus. For ∞, where Ac. is not required, negative Con. must be exerted for fusion and if the condition causes strain we have two remedies. The one is to reduce the accommodative exertion with Cx. lenses, but this would serve only for close work; the other is to increase the Con. by − prisms. Presbyopia arrives early in this condition.

Eso. and H.—As previously described, Eso. is the muscular condition normally associated with H. Con. is easy and requires little effort while the demand on Ac. for clear vision is large. The remedy, therefore, consists of a full correction of the manifest H. and, in addition, sometimes of some of the latent. Every esophoric hyperope, sooner or later, suffers from asthenopia owing to the unequal efforts of Ac. and Con. In low degrees of H. and of Eso., the common period is between 20 and 30; as a rule he requires glasses early, is easy to correct, and becomes presbyopic sooner than is usual. If harmony between Ac. and Con. cannot be obtained by suppressing the Ac. with Cx. lenses, the Con. effort must be increased by − prisms; these, however, are rarely required.

Eso. and M.—This is the unusual condition. Con. being exerted with little effort, it is more or less in harmony with Ac. of which little or none is required if the M. exceeds, say, 3 D. To obtain harmonious action of the two functions, Cc. lenses for constant wear must be of such power as call for little or no Ac. for close work. Reading glasses or those for constant use should be considerably weaker than the full correction.

Exo. and Em.—If the muscles are at rest there is slight divergent strabismus and, to maintain binocular vision at ∞, Con. must be exerted while Ac. is at rest. If the condition causes strain owing to the unequal efforts of Ac. and Con. we can either increase the Ac. effort by the use of Cc. lenses or we can reduce the Con. effort with + prisms. The former is, of course, out of the question although frequently concave lenses are apparently required owing to spasm of Ac. as a result of the Exo. Presbyopia generally arrives late in life in this condition.

Exo. and H.—This also is the unusual association of conditions. Con. is difficult and calls for considerable effort while Ac. is also largely required, so that, more or less, there is harmonious action of the two functions. The H., if not very high, does not need correction until comparatively late in life—only indeed when the presbyopic age is approached and the crystalline responds less freely to the ciliary action. The condition is troublesome, but in general the remedy is to considerably under-correct the H. so that there may still be required an effort of Ac. equal to that of Con. If, owing to under-correction of the H. clear vision is not obtained, a fuller correction must be given associated with – prisms to increase the Con. effort. Presbyopia is usually delayed beyond the normal age.

Exo. and M.—Con. is difficult while no Ac. is needed and therefore no effort made. Con. is rendered easier by stimulating the Ac. with Cc. lenses; but Ac. may be difficult and little may result from considerable effort, so that the remedy consists of giving, for near work and constant wear, those Cc. lenses which are as nearly as possible the full correction of the M. and yet allow of easy and clear vision at the reading distance. These lenses further remove the distance at which near work is done and so reduce the quantity of Con. required. If, notwithstanding the spherical correction which increases the Ac. effort, discomfort still remains, + prisms must be combined in order to lessen the Con. effort. They are much more often needed than – prisms with H. If with correction, fusion in near work only is still difficult, prismatic aid may sometimes be indicated for near work only as a temporary measure to produce fusion. This applies especially in periodic squint when the eyes become fatigued. Once corrected, the exophoric myope uses his glasses constantly and with comfort for all distances.

Near and Distance Tests.—The muscular balance shown in the near may, or may not, be the same as in the distance test and differences in the two can be assigned to either excessive or deficient accommodative convergence, or to the influence of the corrective lenses.

For example, suppose in Em. there is Ortho. for distance; when 3 D. Ac. are exerted for 33 cm., there should also come into play 3 M. A. Con. If the latter be not this correct quantity from which fusion results some supplementary or fusion Con. must take place, and this is positive if the accommodative Con. is less than the Ac. and is negative if the accommodative Con. exceeds Ac. Excess or deficiency of accommodative Con. is shown in the near test in addition to the initial positive or negative Con. shown in the distance test.

If there is more Exo. or less Eso., the accommodative Con. is deficient, while there is an excess of the latter if there is less Exo. or more Eso. in the near than in the distance test. If there is perfect balance in the distant and imbalance in the near test, the latter must be wholly accommodative. If the reverse occurs the accommodative imbalance rectifies an opposite initial imbalance. In H. it is not infrequently the case that Eso. is greater in near vision, that manifested in the distance test being termed *static* anb that induced by Ac. for near vision being *dynamic*. The usual treatment of fullest correction of the manifest H. is the remedy in order to suppress undue Ac. and therefore the associated Con. Similarly, in M., there is frequently higher Exo. in near vision and again, that shown in the distance test is *static* and the accommodative addition is the *dynamic*. Here also the remedy is the usual one of increasing accommodative action by a fairly full correction of the M. thereby making the associated Con. action easier.

If the age is presbyopic, more Eso. or less Exo. in the near test indicates the need of presbyopic correction, or a fuller correction as the case may be —also that the frame may well be *not too narrow*. The reverse is indicated by less Eso. or more Exo.

Spasm of the weaker muscles in near vision may cause apparent difference in the two tests in the direction of lessening the imbalance or even of causing the opposite condition of imbalance. For this reason, mainly, subject to what is stated in the next paragraph, no special attention need be given to the near test, until the use of corrective lenses has been tried, because the latter should remove the cause of the spasmodic muscular action.

Corrective lenses themselves may be the reason for the apparent difference in the distance and near tests; firstly by their influence on the accommodative effort and therefore on the associated convergence effort, and secondly, by their prismatic action when the eyes are converged. The lenses are truly corrective if they tend to lessen Eso. or Exo. and are too full a correction if they tend to produce the opposite condition of imbalance referred to later. For this reason the near test is of importance. It is, however, difficult to separate the influence of the accommodative convergence from that of the corrective lenses, although it may be shown if the muscle tests be made with and without lenses. If the difference exists without lenses it is due to accommodative effort and if shown only when the lenses are up, it is due to their influence. Dependence must, however, be mainly on the distance test and small differences in the two should be ignored.

As quite an exceptional condition there may be Eso. in the one test and Exo. in the other. If the cause lies with the corrective lenses, as previously mentioned, they must be modified in power. Suppose a case of fully corrected H. with Eso. in the distance test; in near vision, the Ac. being suppressed to a certain extent, the Con. might lag to produce Exo.; the remedy is less + power for constant use. Or suppose there is M. with Exo. in the distance test and a full correction be given. Then in near vision the accommodative effort may induce too much Con. and the near balance test shows Eso.; the remedy is to under-correct. From a theoretical aspect one might conceive the existence—owing to excessive or deficient accommodative Con. and excluding the influence of correcting lenses—of true Exo. for distance and Eso. for near or *vice versa.* It would be a rare anomaly and, in theory, the remedy would consist of different correction for near and distant vision, or of prisms for use only in either near or distant vision.

Correction of Vertical Insufficiency.—Vertical defects are more likely to cause discomfort and, therefore, to need prismatic aid than horizontal ones and especially because no assistance is obtained from lenses. Since, however, low and even high degrees may cause no inconvenience, no vertical prisms should be given until the effect of corrective lenses for the cure of asthenopia has been given a fair trial.

Tests should be made on different occasions before deciding what is the measure of the defect; this being decided, a certain portion of it should be corrected, the power being equally divided between the two eyes, the prism being base up for the one eye and base down for the other. In low degrees, say up to 1^{Δ}, the whole may be given to the one eye.

At the most not more than 1/2 or 2/3 of the measured defect should be corrected and anything higher than 2^{Δ} for each eye is rarely tolerated owing to prismatic distortion and dispersion. These aberrations are less noticed when the power is divided between the two eyes.

Correcting Horizontal Insufficiencies.—Prisms should never be given for horizontal defects until a full trial of the correcting lenses has been made, since the troubles they occasion are generally cured by lenses. Only if the correction fails to relieve the discomfort should the use of prisms even be considered. Correction of a refractive error does not act directly but indirectly on the muscles by harmonizing the Ac. and Con. efforts; the lenses thus relieve muscular strain and help the *weaker* muscles to regain their natural functional strength. Prisms cannot cure muscular insufficiencies, but only relieve them by allowing the eyes to squint while still retaining binocular V. If relieving prisms have any effect on the muscles it is rather in the direction of further weakening an already weakened function. Insufficiencies may often be benefited or cured by exercise as described at the end of this chapter. Tests made with the correcting lenses sometimes show lower degrees of Hetero. than without, especially for near distances. The imbalance varies if tests be made on different occasions and at different distances as already described. Consequently under all conditions the imbalance should be considered, if lenses fail to relieve and prismatic aid seems to be indicated. When its measure and nature are decided, an amount not exceeding *one-half* may be relieved, but seldom can more than 3^{Δ} each eye be worn with any comfort. Prisms employed as a temporary measure are sometimes useful in high exophoria which approaches, in degree, a divergent strabismus (vide *Periodic Concomitant Strabismus*).

A low prismatic power may be given to one eye, but it is usual and better to divide it equally between the two. By so doing chromatic effects and distortion are made less appreciable and the plane of fusion corresponds to the median plane of the face, which does not obtain when the whole prism power is before the one eye. In the latter case the convergence or divergence, produced by the prism, is necessarily accompanied by lateral displacement of the eyes. The prismatic effect for the relief of horizontal Hetero. may be obtained wholly or partially by decentring spherical lenses or sph.-cyls. if the principal meridians are Hor. and Ver., or by employing frames which are too narrow or too wide. Similarly, artificial imbalance may be produced by improper frames or lenses.

It is impossible to give a single frame exactly centred for both near and distant vision. In order that muscle strain may be eliminated, so far as possible, with glasses used constantly, the interpupillary distance should be as for distance in Eso. H. and in Exo. M. because, when the eyes are converged for reading, there is the effect of a − prism in the first and a + prism in the second case. In Exo. H. and Eso. M. the frames should be centred for vision at the reading distance, because, for fixation beyond that distance, there is, respectively, + prism and − prism effect. In all cases the frame adjustment should be such that no strain is thrown on the *weaker* muscles.

If one horizontal muscle is weak, the head is sometimes carried sideways, to the right for inefficiency of the external of the right or internal of the left eye, to the left for inefficiency of right internal or left external. That is to say, the head is turned towards the deficient muscle, as, by so doing, the latter is allowed to relax more or less, or is not called upon to make an effort to preserve balance of the eyes. Rotation of the head has the same effect as a relieving prism if one eye only is affected.

Compound Imbalances.—If there is a vertical and a horizontal imbalance to be relieved, each is considered apart from the other and the combined prismatic effect can be obtained from resultant oblique prisms (see " General and Practical Optics ").

Notes on Relieving Prisms.—Summarizing much of the foregoing it can be said that—

(*a*) As a rule prisms are not required and they should never be given simply because Hetero. exists; their necessity must be clearly indicated. Their use is often unsatisfactory and harmful.

(*b*) To determine their necessity, tests must be made with and without corrective lenses in both distant and near vision and on different occasions. From the sum of these a decision may be arrived at.

(*c*) Dependence should be made rather on the distance than on the near tests, and on that made with corrective lenses.

(*d*) One is never quite certain as to the true muscular balance until corrective sphericals and cylindricals have been used. Nervousness may increase the apparent degree of Hetero.

Low degrees of insufficiency generally require no treatment or correction; high ones require rather exercise or operation than prismatic aid, yet sometimes great relief and comfort is obtained from the latter. As a rough guide the limits of prismatic aid lie between a pair of $\cdot 5^{\Delta}$ and of 4^{Δ}.

If there were perfect balance of the external and internal recti a given prism, say 3^{Δ}, should cause, in the groove test, as much deviation when placed base in as when placed base out. This frequently does not occur.

Although with ordinary prisms the effect is small, yet there is increased distortion when looking through them obliquely, as when the eyes are lowered and converged for reading, and if the prisms are vertical the effect of the one and the other is different since the base of the one and the edge of the other is nearer the object. A fuller discussion of this, and the true deviating effect of prisms on the eyes, is discussed in another chapter.

Euphoria, Kataphoria, Anaphoria.—The eyes should be capable of rotating together, from the position of rest, about 35° upwards and 55° downwards, and normal vertical binocular rotation is termed *euphoria*. It rarely occurs that the total vertical rotation is much less than about 90°, for if the one excursion is limited, the other is increased, but there may be a limitation in one or both directions. When the muscles are at rest the normal vertical inclination of the visual axes is said to be 12° to 15° above the horizon; it is very difficult to confirm by measurement. The inclination is partly due to the normal deviation of the visual above the optic axes.

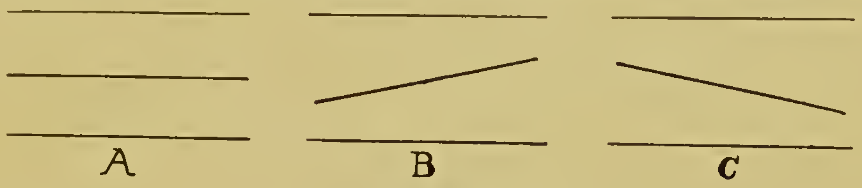


Fig. 62.

If the eyes have a tendency to droop, or if there is difficulty in raising them, the condition is known as *kataphoria*; if there is difficulty in lowering them, there is *anaphoria*. The condition may result not only from anatomical imbalance of the muscles, but also from an abnormal position of the eyes in their sockets or of the maculæ; a permanently depressed or elevated chin may indicate its presence. Equal power lenses in a frame which is too high or too low may artificially produce the condition.

If there is a tendency towards Kata., Cx. lenses should be higher and Cc. lenses lower; if there is Ana. Cx. lenses should be lower and Cc. higher. By so doing there is a certain amount of prism power produced base up in the first case, base down in the second. These effects can be obtained by raising or lowering the bridge.

Cyclophoria is insufficiency of the oblique muscles. If one of the latter is affected, torsion occurs owing to the partially unopposed action of the antagonistic oblique. In these circumstances horizontal and vertical lines are seen more or less inclined.

For testing Cyclo. the double prism is used with a single horizontal line as the test object at 6 m. and 1 m. Before testing the obliques any vertical and horizontal insufficiencies must be corrected and the double prism is placed base horizontal in front of the one eye. Two horizontal lines are then seen by the latter, one above and the other below the single line viewed, in the ordinary way, by the uncovered eye. Both eyes must be tested separately, the one under test being that before which the double prism is *not* placed, *i.e.*, the eye seeing the central line. The tests must also be made with, and without, correcting lenses especially if these contain oblique cyclindricals, as is usually the case if Cyclo. is present.

If there is no Cyclo. the three lines are seen parallel but should there be oblique insufficiency the central line is apparently inclined with respect to the others, as shown in Fig. 62 illustrating (A) Orthophoria, (B) Insufficiency of the left inferior or of the right superior oblique, (C) Insufficiency of the left superior or of the right inferior oblique.

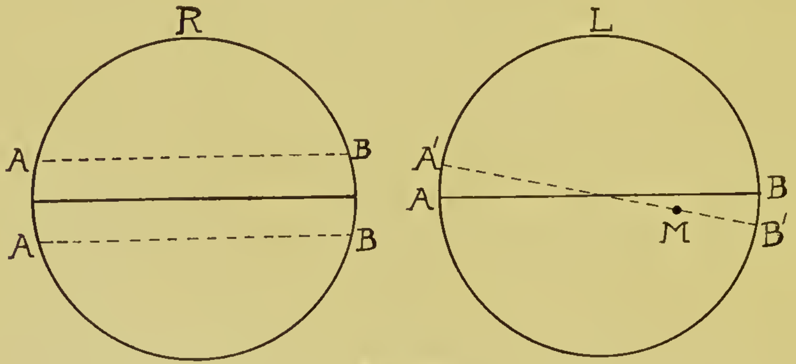


FIG. 63.

Suppose in the left eye there is insufficiency of the superior oblique; then the unopposed action of the inferior oblique rotates the horizontal meridian, at the retina into the position *A′ B′*. As shown in Fig. 63, the retinal image *AB* of a horizontal line is then, owing to the torsion of the eye, *relatively* below on the nasal and above on the temporal side with reference to the true horizontal *A′ B′*. The image projected is therefore inclined above on the temporal and below on the nasal side of the field and is thus seen with respect to the double lines viewed by the right eye, as in Fig. 62 C. The indication given by the test can be memorized thus: The central line inclines, on the temporal side, towards the weaker of the obliques, or it points on the nasal side in the direction of the stronger. In Cyclo. it is very difficult to determine whether there is actual insufficiency of muscles or malposition of image owing to oblique As. False torsion increases with convergence and, of course, it may augment or tend to rectify the real torsion caused by deficient oblique muscles. Torsion found by this test at 5 or 6 m. should be considered in connection with that found at, say, 1 m. or somewhat less. If torsion is thus found only at a near distance, it may be generally ignored unless the distortion of straight lines be very great in ordinary vision. Cyclo. results chiefly from oblique As. and cannot be measured or corrected by prisms. Its remedy is referred to in Chapter VII. and under Muscle Exercises. Symmetrical insufficiency of the two superior obliques would cause two parallel vertical lines to incline towards each other above; insufficiency of the two inferior obliques would cause them to incline towards each other below. Inclination of the head over towards the one or other shoulder indicates Cyclo. as well as oblique As., with which it is intimately connected.

Another test for Cyclo. is to put a Maddox groove vertically before each eye and, say, a 4△ prism base down in front of one eye; the two streaks seen should be brought one above the other by changing the distance between the grooves. Then the two streaks are horizontal and parallel if there is no Cyclo., but if the latter be present they are mutually oblique, each line inclining, at its temporal extremity, in the direction corresponding to the inefficient oblique. The rotation of the grooves necessary to make the streaks horizontal and parallel can then be made to indicate the degree of Cyclo. Care must, however, be taken that the grooves are initially exactly vertical.

High Hetero.—Should persistent asthenopia remain notwithstanding correction of the Am. by lenses, relief by decentring or weak prisms, exercise of the weak muscles, or an operation may be required. Whether an operation, relief by prisms, or exercise be the remedy in the higher degrees of Hetero., is a matter for consideration by the ophthalmic surgeon. No surgeon would, however, decide on an operation until the effect of lenses has been tried. When a Hetero. is of so high a degree as to indicate the possibility of an operation for its cure, it is akin to periodic strabismus (*q.v.*) and, like the latter, is an abnormal condition which perhaps cannot be corrected by merely altering the course of entering light. It is, therefore, beyond the scope of non-medical treatment.

Strabismus.

Strabismus is the condition where the two visual axes are not, at the same time, directed towards the same object. In Hetero. there is simultaneous binocular fixation, in strabismus there is not. The causes of strabismus have been given, in general, for both classes of muscular imbalance (*q.v.*) but, in addition, absence of the fusion faculty or anything such as nebula, which renders fusion impossible, acts as a cause. Besides this we may include congenital amblyopia, diseases of the eye, paralysis, hysteria, nervousness and general disease.

Nomenclature.—Strabismus convergens—esotropia—when the one eye turns inwards.

Strabismus divergens—exotropia—when the one eye turns outwards.

Strabismus ascendens or sursumvergens—hypertropia—when the one eye turns upwards.

Strabismus descendens or deorsumvergens—hypotropia—when the one eye turns downwards.

Divisions.—In general, we can divide squint into *concomitant* or non-paralytic, and *incomitant* or paralytic.

Non-paralytic squint is usually due to refractive errors, but there are also other causes for non-fusion of the images. Absence of fusion may have its origin in the brain and be either congenital or acquired so that, there being a tendency thereto, the one eye wanders; disease, injury or amblyopia renders one image imperfect or faint and the one eye deviates because the two images cannot be fused. Absence of fusion may be due to the fact that monocular is better than binocular vision, suppression of the one image being best obtained by deviation of the defective eye; or because weakness of a muscle or muscles renders fusion impossible or too painful. Similar influences may be found where there is an error of refraction, but the latter may not be present, or at least it may not be the *main* cause of the squint. This condition, like that of the paralytic variety, has no close connection with optical work and needs rather medical treatment; non-paralytic squint will be considered, in this chapter, in its connection with H. and M. When Am. is not the cause of the squint, the latter may appear at any period of life and, in this respect, especially when it is convergent, there is considerable difference from that due to Am.

Apparent Strabismus is the condition caused by angle α being abnormally large or small. The former causes an apparent divergence of the eyes and is usually associated with H.; the latter causes an apparent convergence and usually accompanies M. In this condition the *optic axes* have a greater or lesser degree of divergence than is normally the case, and they may still diverge, although, as compared with their appearance associated with a normal angle α, they appear to converge.

Ophthalmoscope Test.—If the subject, with his back to a window, looks at a Cc. mirror held about 50 cm. away and in the median line, the optician will see through the aperture of the mirror a bright spot reflected from the cornea of each eye, the spots being asymmetrical when there is a squint. If there is no squint they are symmetrical and lie on the visual axes, generally a little to the nasal side of the pupillary centres.

Pencil Test.—A pencil or other small object is slowly approached towards the eyes which fix it. If there is squint (or high Hetero.) the one eye may stop converging and then deviate when the pencil is near. The latter should also be thus moved directly in front of each eye alternately, for then the other eye apparently converges to twice the extent and its action is more clearly observed.

The Card Test.—Let a distant object be viewed and the left eye occluded with an opaque disc or card; if now the right eye makes no movement it was previously fixing the object. The left eye is uncovered and, at the same time the right is occluded with another disc or card; if the former makes no movement to fix the object it was not deviating when occluded. Absence of movement of either eye shows absence of strabismus, while movement of one or both eyes in order to fix, determines squint *or* Hetero.

Primary and Secondary Deviations.—In the card test, if there is a squint, the deviation of the bad eye, when the good eye fixes, is called the *primary* deviation. When the bad eye fixes, the good eye being occluded, the deviation of the latter is the *secondary* deviation.

To Recognize Concomitant Squint.—(*a*) The deviation of the one eye is easily and at once observed (except in the periodic variety).

(*b*) There are rarely complaints of double vision (except in periodic squint).

(*c*) The primary and secondary deviations in the card test are equal.

(*d*) The angle between the visual axes is constant.

(*e*) The excursions are equal in all directions and the one eye never stops with a jerk

(*f*) The head is rarely held inclined.

Nomenclature of Concomitant Squint.—This is said to be—

Periodic when the squint is not always present. It is also termed *intermittent*, *inconstant*, *recurrent*, *occasional* and *relative.*

Constant when it is always present; also called *fixed* or *absolute.*

Alternating when each eye alternately fixes and deviates; sometimes termed *binocular* squint.

Monolateral when the same eye always deviates; otherwise called *unilateral*, *monocular*, or *uni-ocular*.

Periodic Squint, when concomitant, is usually the forerunner of the constant type. It may, however, never develop into the latter and therefore may be found at any period of life. It is, at times, a latent and, at others, a manifest deviation and is therefore intermediate between Hetero. and constant squint. It may be considered as Hetero. of high degree. Accommodative squint, or spasm of convergence, which occurs only in near vision, is one form of periodic strabismus which may also be of a hysterical or nervous nature, or the result of disease.

Alternating Squint.—Most cases of strabismus are alternating before becoming monolateral, but since a case may never develop into the latter, the condition may be met with at any period of life. In alternating squint the visual acuity, almost without exception, is equally good in both eyes, this being the reason why the squint remains alternating. The cause may lie in the congenital or acquired absence of the fusion sense, the refractive condition being anything from Em. to high antimetropia (*q.v.*). The usual form, however, occurs in equal H. or M. in which the acuity of the eyes is equal and with, or without, the fusion sense. If the latter be absent the squint can be cured by operation only.

Monolateral Squint.—Here one eye only is used, the other being deviated in distant and near vision. Almost invariably the deviating eye is more or less amblyopic and generally has the higher refractive error.

Suppression of the False Image.—When there is deviation of the visual axes with respect to an object, the latter cannot have corresponding images in the eyes. Therefore diplopia must result if there be simultaneous binocular vision because, while the one image is macular, the other is not, and is projected to a different place in space. In constant concomitant strabismus, diplopia does not occur because the image of the squinting eye is mentally suppressed. The deviation of the one eye is the result of a circle of cause and effect in that, in order to rid itself of the confusion caused by the false image, the brain impulses turn the eye over to a greater extent, so that the image may be formed as far as possible from the macula and on the comparatively insensitive retinal periphery. The deviation of the squinting eye is generally very considerable. Even if a false image be seen by the squinting eye, it is so faint and so remote from the clear image obtained by the fixing eye that it has no more effect than the impression received, in ordinary binocular vision, of objects in the periphery of the field. It is the continued non-use of the squinting eye that causes amblyopia-ex-anopsia.

Amblyopia.—This term is applied to reduced vision not caused by active ocular disease and incapable of improvement by lenses or other optical aids. It may also result from general disease, poisons, drugs or tobacco. Partial amblyopia may be due to high Am. especially if long uncorrected, and it is then usually more or less binocular.

The monocular form may be congenital and the cause of a squint, or a squint may be the cause of a monocular amblyopia. If there is congenital monocular amblyopia and perfect muscular balance no squint would result; but if there is muscular imbalance, with absence of the stimulus of binocular fixation, the eyes wander into their position of rest, which may be that of either convergence or divergence. On the other hand monocular amblyopia is generally acquired and is the result of non-use of the one eye due to squint; the term amblyopia-ex-anopsia is applied to this class. Should there be squint and amblyopia of one eye, the former most likely has resulted from the amblyopia, if the latter is equal on both sides of the macula. If the insensitiveness to stimulation is greater on the one side of the retinal field than the other, the amblyopia has resulted from non-use on account of the squint. In this latter case the temporal side of the retina in convergent, and the nasal side in divergent, strabismus is the more defective. In alternating and periodic strabismus there cannot be amblyopia-ex-anopsia, but there may be partial and more or less equal amblyopia in both eyes.

To reduce partial amblyopia in one eye it should be daily exercised, as described under ocular exercises (*q.v.*).

The Measurement of Squint can be made by the strabismometer and more accurately by the perimeter.

Fig. 64.

The strabismometer (Fig. 64) is made of ivory or metal and shaped to fit beneath the edge of the lower lid. The good eye being occluded, the zero of the scale is placed beneath the centre of the pupil of the squinting eye while the latter is directed towards a distant flame, the object being placed on the median line. The good eye is now uncovered and fixes the flame while the squinting eye deviates. The position of the centre of its pupil then gives the measure of the squint, in degrees or mm., by the number on the scale over which it is situated. This is the primary deviation, *i.e.* that of the bad eye when the good one fixes. To measure the secondary deviation, *i.e.* that of the good eye when the bad one fixes, the instrument is placed with its zero beneath the centre of the pupil of the good eye while it is fixing; the latter is then occluded and the deviation that occurs, when the worse eye turns in order to view the object, is read on the scale. The strabismometer is useful for the measurement of horizontal squints only. A small rule serves, although roughly, the same purpose as the strabismometer.

The *perimeter* has been elsewhere described. To measure a squint with it, the angle γ or κ must be first determined. If an eye is too amblyopic to fix, the angle γ or κ can be measured on the good eye and taken to be the same in the bad eye.

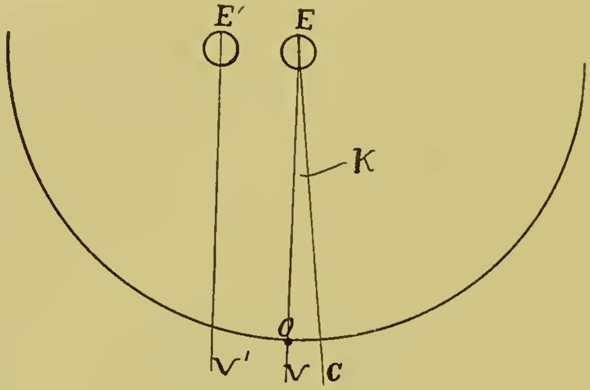


Fig. 65.

The one eye E' being occluded, the other E which is to be measured is placed in the centre of the perimeter, and fixes O the central spot or aperture. A lighted candle C is moved round the arc until its image is seen in the *centre of the cornea* and the angle γ is indicated on the notation of the arc. It is, however, much easier to locate the image in the *centre of the pupil* and the angle then obtained is κ which, for all practical purposes, is identical with γ.

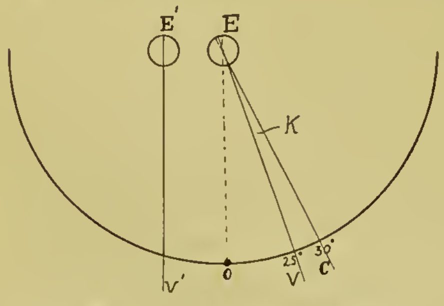


Fig. 66.—Divergent Strabismus.

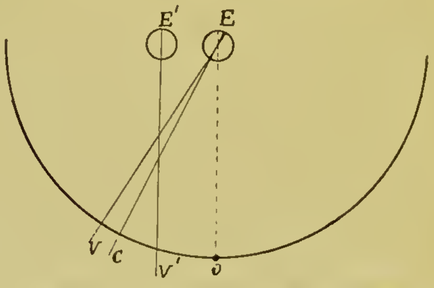


Fig. 67.—Convergent Strabismus.

To measure a squint, which is the deviation of the one visual axis from parallelism with respect to that of the other eye, it would be necessary to locate the visual axis, but this cannot well be done. We can, however, measure the angular distance between the zero of the arc and the position of the pupillary line and from this, knowing angle κ, we can determine the degree of squint. The squinting eye E is placed in the centre of the perimeter (Figs. 66 and 67) and the eye E' views a distant object placed in line with the centre O of the arc. A flame C is moved around the arc of the instrument until its image is seen in the centre of the pupil of the squinting eye of which *VE* is the visual axis. The angle indicated is that between zero and the corneal line *CE* so that, as shown in Fig. 67, angle κ must, in convergent strabismus, be added to and, in divergent squint (Fig. 66) deducted from this angle in order to obtain the angular degree of squint.

Subjective Measurement of Squint.—The Maddox groove is placed in front of the good eye and the bad one fixes a flame; the deviation of the streak is then measured either on a large tangent scale or by the power of the prism which combines the two images. This test is difficult if the squint is of high degree or if the one eye is amblyopic, and becomes impossible if binocular vision does not exist.

Cure of Concomitant Squint.—Since the squint is usually the result of Am., correction of the latter is sometimes a cure for the former; otherwise operation must be resorted to. Even if an operation be made corrective lenses have to be worn constantly because, if not, the squint may return. Sometimes the eyes remain straight only so long as the lenses are in front of them and deviate immediately they are removed. This is specially so in those cases which have been cured without operation. Even a bent frame, or a dirtied lens, which prevents binocular vision, may cause deviation of the one eye. The cure of a pronounced squint involves improvement of vision in the amblyopic eye (thus producing simultaneous binocular vision), restoration of balance by operation, exercise of the muscles first with stereoscopes, and then without, so as to obtain single binocular vision and enforced binocular reading. After an operation there may be diplopia owing to want of exact parallelism of the two visual axes; this is cured by exercise, etc. Also a false diplopia may obtain when the operation has caused the visual axes to be parallel, but such diplopia usually soon disappears. The cause of the latter is that a squinting eye may project the image through the nodal point along some line other than the true visual axis, it having developed a kind of false macula in the sense that some other portion of the retina had become and is still, for the time, after operation more sensitive than the true macula.

Convergent Concomitant Strabismus.—This is the commonest form of squint and although it may, owing to other causes, be found with any refractive condition of the eyes, the optical condition is usually that of H. and the latter is generally the direct cause of the squint. There may be contributory influences, as, for instance, an unequal degree of H. and therefore of vision in the two eyes, a disease or a nebula of the one eye, hysteria, nervousness or illness, but the main cause is the refractive condition.

Hypermetropic convergent strabismus usually commences at the age of 2 or 3 years—sometimes even earlier—in fact so soon as the child commences to learn the value of clear vision; it very rarely occurs after the age of 6. In order to obtain clear V. in H., some Ac. must be exerted for ∞ and, if equal Con. be exerted, the eyes are converged for a point nearer than that for which vision is clear. Suppose a case of H. 2 D.; to see at ∞, Ac. 2 D. must be exerted and if it be accompanied by a 2 M. A. Con. the point of binocular fixation is 50 cm. while that of Ac. is ∞. It being impossible to have binocular vision at ∞ or clear vision at 50 cm., there must result either a greater action of Ac. than of Con. with clear binocular vision, or equal Ac. and Con. with blurred binocular vision, or equal Ac. and Con. and clear monocular vision. Thus every hypermetrope, when young, must unconsciously elect between (1) clear binocular vision probably with discomfort, (2) impaired binocular vision and (3) clear monocular vision with a squint. The usual condition is the first, for only a very small proportion of hypermetropes actually squint and most of them have clear vision. It is true that the majority of them have Eso. as a result of obtaining clear binocular vision, but training seems to have the effect of bringing about inequality of result with equality of exertion without Asth. The unconscious selection of this condition must result from the fact that accommodation in excess of convergence is possible in low H. and is not too painful. In medium degrees of H. likely to cause squint, the ametrope, having unconsciously learnt that clear binocular vision is impossible or too painful to achieve, chooses between blurred vision, *i.e.* absolute H. without a squint, and clear vision, *i.e.* relative H., with a squint. The deciding factors are usually the degree of error and inequality of error in the two eyes; in fact, upon the former depends, almost exclusively, which of the three conditions given above shall be present.

We must not, however, lose sight of the possible effect of *intelligence* in this connection because, whether a coincidence or not, it certainly seems a fact that, the lower the social scale—*i.e.* the nearer it is to that in which normal vision is not 6/4—the more prevalent is the condition of convergent strabismus. It is quite probable that when the question of squint or no squint, as it were, hangs in the balance, the inherent intelligence or mental activity of the child decides the point, preferring binocular clear, although difficult vision, whereas a sluggish and backward intelligence would elect to squint and thereby easily obtain comfortable, though monocular sight.

As a rule a degree of H., not exceeding 3 D. in young people, is facultative with clear binocular V., an error between 3 and 5 D. being the amount most likely to produce convergent strabismus; H. of more than 5 D. would very probably be absolute even with the high Amp. of accommodation of youth. Of course, there are exceptions and the foregoing can only be taken as an approximate rule, but it is the exception to find convergent strabismus in H. under 2 D. or over 6 D.

It is not difficult to understand why these conditions result. When in small differences, it is possible for Ac. to be exerted in excess of Con., we find clear binocular vision. If the degree of H. be medium, say 3 D. to

5 D., the difference is too great, so that vision is clear but monocular, there being convergent strabismus. In the high degrees—those over about 5 D.—we can understand that the excessive Ac. alone needed for clear V. is so difficult or painful, even if accompanied by equal Con. that the effort is abandoned and preference is given to blurred binocular V. Again, if there is unequal binocular V. in any circumstances, as when one eye is amblyopic or has the higher ametropia, that eye is allowed to wander and the whole attention concentrated on clear monocular vision with the better eye.

The deviation of the squinting eye, expressed in metre angles, is not, however, merely equal to the diopters of H., but greatly exceeds it. This results because the external recti are already functionally weaker than the internal, so that, so soon as fusion is abandoned, the *stronger* internal recti deviate the squinting eye to the position of rest, and such deviation is the total of the two eyes. Further, the squinting eye is unconsciously deviated still more, or as much as possible, in order that its image may be formed as remote as possible from the macula. As before stated, this facilitates the suppression of the image because it is then less clear, and projected as remote from the object seen clearly by the undeviated eye. Thus in H. 3 D. with convergent squint, when the one eye fixes an object, the other is deviated to an extent greater than 3 M. A.—probably 10 M. A. or more.

If periodic, the squint may occur in order to make vision clear, or when fatigue of the external recti causes them to relax their usual tension. It may occur only in near vision, the eyes not deviating for distance, either because Ac. can be exerted in excess of convergence for ∞, or because, for distance, the H. is allowed to be absolute and vision binocular. Sometimes, though rarely, one may find a high error with a low degree of squint but the sense of fusion would probably be absent.

Cure of Convergent Strabismus.—If caused by H., the correction of the refractive error should, in theory, cure the squint. In practice it is not so easy because—

(*a*) The angular deviation of the squinting eye in metre angles is far greater than the existing H. expressed in diopters.

(*b*) The visual acuity of the deviating eye is lowered.

(*c*) The fusion sense is diminished or lost.

The successful issue to an attempt to cure convergent strabismus with Cx. lenses depends essentially on (*b*) and (*c*).

The amblyopia produced by the squint depends on the length of time the latter has existed, or rather on the time it has been monolateral. The loss, or suppression, of the fusion sense depends similarly on the duration of the squint. Thus the *age* of the subject is the all-important factor in the possibility of the cure of convergent concomitant squint by means of Cx. lenses. If the squint is of long standing so that the one eye is highly amblyopic, or if the fusion sense is lost or had never existed, any attempt to cure the squint by lenses is hopeless. Nevertheless Cx. lenses will sometimes reduce the degree of deviation and make it less disfiguring and, of course, operation will have that effect in any case. As a rule in adults, and always in children, it is necessary in convergent strabismus to measure the refraction under a cycloplegic. In addition, the eyes require to be kept for a time under the influence of drugs and the lenses first used when Ac. is at rest. Further, the question of whether, or not, operation is indicated is one for a surgeon's decision, so that from all points of view squint should not be treated by the optician if an ophthalmic specialist is available.

Seeing that the above factors (*b*) and (*c*) are the main difficulties in the cure of squint it follows that, as compared with the constant monolateral type, periodic and alternating strabismus are much easier to cure with lenses because, in these conditions, the one eye has not become amblyopic; it is essential, however, that the fusion sense should exist. With respect to the lenses themselves the important points are (1) that the spherical correction should be as full as possible and any existing As. be fully corrected, and (2) the lenses should equalize the accommodative action and, as far as possible, the visual acuity of the eyes. The lenses must be worn constantly. Some time—a few weeks—must elapse before it is possible to say whether lenses will, or will not, cure a convergent squint without operation.

Convergent Squint in Children.—The optician is often consulted upon this point, and the only conscientious advice to be given is that an ophthalmic specialist be consulted. Glasses cannot well be given to a child before he is 3 or 4 years old, and if the child is younger there is danger of amblyopia and loss of the fusion faculty in the meantime. The use of cycloplegics is of prime importance in this connection.

Spontaneous Cure.—It would be rash to even suggest that a squint in a child will disappear of its own accord. Nevertheless such cases, although rare, do occur, but even then the one eye may be amblyopic and useless for vision; also squint occasionally becomes lessened, or even disappears, in old age—at least it is not an uncommon occurrence to meet people with normal balance who assert that they used to squint, and that they have never had any kind of treatment for its cure.

Infantile Squint.—Many babies before they learn to fix, or observe clearly, have periodic strabismus. This disappears as soon as the fusion sense is developed.

Divergent Concomitant Strabismus.—Occasionally this condition is met with in H. or Em., but usually it is the result of uncorrected M. produced in the same way as Exo. in that condition. The age at which *myopic* concomitant squint appears is between, say, 16 and 24 years; before this the degree of M. is not generally, so high as to induce strabismus.

The excessive amount of Con. demanded in M. without the necessary innervation of Ac. causes the internal recti to become functionally and, perhaps, actually weakened. This weakness increases with the degree of M. itself for, as the reading-point approaches still nearer to the eyes, the difficulty with Con. becomes still more pronounced. Ultimately the myope learns that he can relieve the asthenopia by holding print to one side and employing only the one eye for reading. The other eye is then allowed to turn outwards and, the external recti being relatively stronger than the internal, the amount of divergence which ensues is much greater than would result from the use of one eye only in orthophoria or even exophoria, as when looking through a telescope or microscope. At first the resulting squint is periodic in that it occurs only when the eyes are fatigued or when, in order to view a very small object, it is brought unusually close to the eyes. Later it becomes permanent for all close work and at this stage it may be alternating, the one or the other eye fixing in turn. This, however, is not very common in divergent concomitant strabismus.

The periodic type of divergent strabismus may be regarded as an exaggerated case of exophoria, which muscular state must exist before a divergent strabismus results. It is demonstrated, as is high Exo., by the pencil test. Later the squint becomes constant and monolateral, one and the same eye being always employed for both distant and near vision ; generally the deviating eye has higher M. or more As. than the other. When the squint is in the periodic stage, there are complaints of more or less transient diplopia as the eyes pass from binocular to monocular fixation. This occurs when fatigue of the internal recti causes them to relax so that, for the moment, the images of the object viewed fall on non-corresponding parts of the retinæ which are sufficiently near to the maculæ to be appreciated. When the squint is constant, there are rarely complaints of double vision ; the image, in the deviating eye, is so far from the macula and is projected into space so faint and remote from the other image that it is therefore ignored or mentally suppressed. Thus the degree of squint is unconsciously increased, and the eye allowed to rove as far as possible in order that the image of that eye may be the more easily ignored. This is facilitated by the habit, indulged in by myopes of high degree with divergent strabismus, of holding a book to one side and reading in a manner somewhat similar to that in which a squirrel views a nut.

The deviating eye, in constant divergent strabismus, soon becomes amblyopic from non-use, but not so rapidly, nor to so great an extent, as in convergent strabismus associated with H. In the first place, it commences much later in life and, in the second, the eye is turned outwards and receives more light from the periphery of the field than in convergent squint. Divergent squint is less likely to result if, prior to the acquisition of M., the muscular balance was anatomically esophoric and more likely if it was exophoric.

Cure of Divergent Strabismus.—If the defect is caused by M. it should, in theory, be cured by correction of the latter, but in practice this ideal is destroyed because (*a*) the deviation in metre angles greatly exceeds the degree of M. expressed in diopters, (*b*) there is amblyopia of the squinting eye, (*c*) there is perhaps a diminished fusion faculty. Nevertheless Cc. lenses tend to cure divergent squint caused by M. In the first place they remove the distance of close work and consequently the necessity for excessive Con.; in the second place they induce Ac. so that Con. is rendered more easy. In the third place, with the lenses, the image in the deviating eye lies nearer to the macula, is sharper, and is projected nearer to the other, so that an effort, which may be successful, is made to fuse them, especially since Con. is a positive function. As in convergent strabismus, the governing factors are the degree of amblyopia of the squinting eye and the presence or absence of the fusion faculty. If the visual acuity of the one eye is reduced and cannot be improved, or if the sense of simultaneous vision does not exist, there is no hope of a cure by lenses, the only remedy being operative. The periodic and alternating varieties, provided the fusion faculty is possessed in the latter, are naturally more susceptible to the correcting influence of lenses. The latter selected should be those which cause near work to be done at as great a distance as possible, say not less than 40 cm.; they should therefore be as strong—up to full correction—as the accommodative power will allow. They must equalize the accommodative action of the two eyes and should equalize the visual acuity if possible, and any As. must be fully corrected. The glasses suited for close work should be worn constantly.

The Use of Prisms in Concomitant Squint.—For the cure of squint prisms are useless, except occasionally for the following purpose. If diplopia is elicited but the two images are too far apart to be fused and the one is faint owing to its position in the deviating eye, prismatic power may be advantageously employed for the purpose of bringing that image nearer to the macula so that it becomes clearer and capable of fusion with the other. Such prisms must, on no account, cause fusion directly but be merely the indirect cause of it. Further, they must be given as a temporary measure only, and must be gradually reduced in strength as the muscles become more balanced in their action. In divergent squint prisms base in are more likely to prove valuable than are prisms base out in convergent squint. If the lenses are strong enough, the same effect may be produced by mounting them in a frame which is too wide and gradually reducing its width. A frame too wide with Cx. lenses gives the effect of − prisms, with Cc. lenses of + prisms.

Operation for Squint.—This consists of tenotomy of the over-acting muscle, or advancement of the weaker muscle, or both. Operation is indicated when lenses, exercise, etc., fail to cure a squint and especially if the latter exceeds, say, 25°. An operation is also sometimes made for the cosmetic effect obtained, although the one eye is quite amblyopic and useless for vision.

If there is simultaneous vision and any reasonable degree of acuity in the squinting eye, operation is not usually resorted to until an attempt has been made to cure the squint without it. Even in convergent monolateral strabismus these conditions may apply up to, say, 15 years of age and in divergent squint at a much later period. In periodic and alternating squint, lenses may effect a cure at any period of life. Occasionally one meets with, say, a divergent squint caused by an operation for the cure of a convergent squint and *vice versa.*

Paralytic Squint.—This is caused by some grave disorder and is a condition which need not be discussed in a non-medical work. A few of the symptoms, however, by which it may be recognized are given. The optician, moreover, may be entrusted by a surgeon with the selection of prisms to enable a person to see singly. Paralytic squint may be constant, or it may be periodic in the sense that it is not noticeable under certain conditions. It is also periodic in its early stages.

The essential difference between paralytic and concomitant strabismus lies in the nature of its origin. In the latter condition there is a relative deviation between the eyes but, once the squint has been set up, all subsequent movements are *yoked*, the angle between the visual axes remaining constant. In paralytic squint, however, only one individual muscle, or group of muscles, is affected, and therefore there is no constant yoked or conjugate action of the eyes in their various excursions ; neither does the angle between the visual axes remain constant for the simple reason that, as the eyes are turned in the direction of the paralyzed muscle or muscles, the degree of squint increases. On the other hand, for a certain lateral or vertical position of the eye there may be no manifest deviation at all and, in fact, a prominent symptom is the carriage of the head towards one shoulder or upwards or downwards, as the result of unconscious effort to keep the eyes turned with respect to the affected muscles, so as to secure single binocular vision.

To Recognize Paralytic Squint.—The deviation is not highly marked on ordinary observation, because the subject turns his head to avoid diplopia. The head is therefore frequently held inclined, there are complaints of double vision and in the card test the secondary deviation is greater than the primary, because then the affected muscle must act and, the great effort needed for fixation by the affected eye being communicated to the sound corresponding muscle of the other eye, a greater deviation of the latter is caused.

When the eyes follow an object moved in different directions the squint, and therefore the diplopia, increases as the object is moved in that direction towards which the affected muscle would normally turn the eye ; it may entirely disappear when the eyes turn in the opposite direction. The excursions of the eyes are unequal in different directions so that, when movement is made towards the affected muscles, the bad eye lags behind the other and stops after making two or three jerky movements. The same may occur in the pencil test. All these are practically the reverse of symptoms of concomitant squint.

Diplopia or double vision results when the image in the one eye does not correspond with that of the other; it may therefore be produced artificially by a prism.

The primary essential of simultaneous binocular and single vision is that the two retinal images should correspond, and this obviously cannot occur in strabismus.

Homonymous or *uncrossed* diplopia results when the left image belongs to the left eye and *vice versa*; it is caused by convergent strabismus. *Heteronymous* or *crossed* diplopia results when the right image belongs to the left eye and *vice versa*, and is caused by divergent strabismus. Diplopia may be also vertical or oblique. The false image is always on the side of the affected muscle, the eye being deviated in the opposite direction.

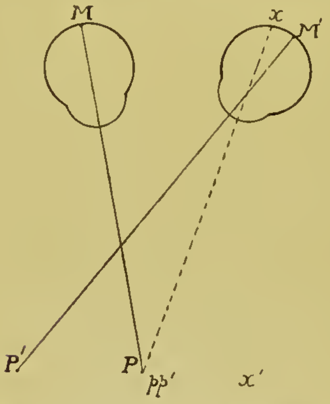


Fig. 68.—Convergent Strabismus: Homonymous Diplopia.

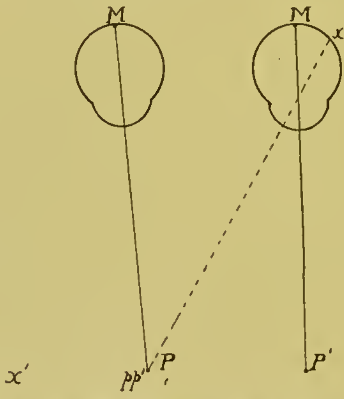


Fig 69.—Divergent Strabismus: Heteronymous Diplopia.

The macular images in the two eyes, whether of the same or of different objects, are always referred to mentally coincident points in space. When in, say, convergent squint of the left eye, it is desired to view an object *P* by the fixing eye, the squinting eye (Fig. 68) is directed towards some other object *P′* so that the macular images *M* and *M′* are mentally referred to two overlapping points *pp′*. The extra-macular image *x* of *P*, *i.e.* the false image seen by the left eye, is referred out to *x′* on the *left* of the coincident images *pp′* and the diplopia is therefore homonymous since the false image is seen on the same side as the squinting eye. The macular image *M′* in the squinting eye is, however, ignored because the attention is concentrated on the object

P. Similarly, in divergent strabismus (Fig. 69) of the left eye, x' is the false image referred out on the right of pp', and as this is on the opposite side to the squinting eye, the diplopia is crossed or heteronymous. In fact, the same reasoning holds good for any deviation, whether lateral, vertical or oblique, the false image being always referred back in space to the same side as the affected muscle or, more exactly, in the direction opposite to the deviation of the eye.

Naturally the separation of the two images is greater as the squint is greater, and if there were diplopia with a concomitant squint the separation would be equal for any position of the object at a constant distance. This is not, however, the case in paralytic squint, where the deviation varies exceedingly for different positions of the object. The diplopia is troublesome and noticeable in the latter case because the two images are, in general, near to each other and the affected eye has not the same opportunity to become amblyopic as in concomitant strabismus. The remedy unconsciously sought is closure of the one eye or inclination of the head, or the diplopia can be removed by the use of prisms. It can be permanently removed only by curing the squint itself.

Determination of the Affected Muscle.—The prism which remedies the diplopia must be placed base towards the affected muscle or obliquely if the diplopia is oblique. It is first necessary to ascertain which is the affected eye and which the affected muscle or muscles.

Place a lighted candle at a convenient distance, say, 6 metres, in the median line immediately facing the subject. Put a red glass in front of the one, and a green glass in front of the other eye so that red and green flames are seen. The head being kept steady, ascertain if the images are level or whether the one is higher than the other, or whether they are separated both horizontally and vertically.

Then move the light in the horizontal plane to the right and left, and ascertain in which direction the images are more separated; the separation is greater on the side of the affected muscle. Ascertain which image is the more remote; this pertains to the affected eye. Thus suppose the red glass is before the right, and the green before the left eye. If the separation is greater when the candle is, say, to the right, then either the right external or left internal rectus is faulty. Suppose the red flame is the more remote; this pertains to the right eye. Thus the affected muscle is the right external rectus. The diagnosis is not, however, always so simple as the foregoing appears, because frequently the deviation is not only horizontal, but also vertical. Moreover there may be torsion of the eye so that the image is seen obliquely.

To Find the Correcting Prism.—Since the diplopia varies with the position and distance of the object viewed and with the position of the head; and since the effect of a prism varies with the inclination of the eye to it, no single prism can be exactly suited for all distances and all purposes ; it should be selected for that position and distance in which it is most required.

If there is only horizontal, or only vertical, diplopia that weakest prism base towards the affected muscle is found which causes fusion of the two images. If there is both horizontal and vertical separation, there should be first found the horizontal prism which brings the two images into the the same vertical plane, and then the vertical prism that causes fusion in the horizontal plane. The two can then be resolved into a single resultant prism. It is better to divide the power of the prism between the two eyes, as would be done for Hetero., for then the fused image is projected to the median line which is not the case if one prism only be used. Also distortion and chromatism are not so pronounced.

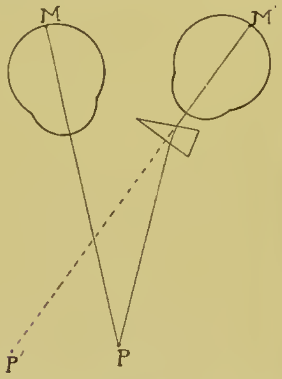


Fig. 70.—Uncrossed Diplopia corrected by Prism Base out.

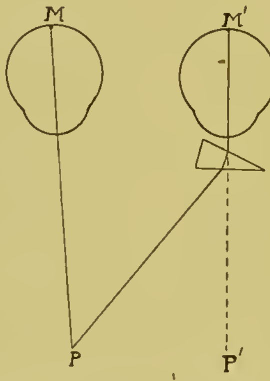


Fig. 71.—Crossed Diplopia corrected by Prism Base in.

The correcting prism produces single vision by bending the incident light from the object so that, on entering the eye, it forms an image on the macula ; then the two images correspond and are fused into one as shown in Figs. 70 and 71.

Position of the Head.—Diplopia disappears in paralytic squint when the object is situated, with respect to the eyes, on the opposite side to the affected muscle. Thus if the right external rectus were affected, there would be no double vision of an object when it is moved to the left, because both eyes can turn to the left and fuse the images. Instead of turning the eyes, the same effect is produced by turning the head in the opposite direction, *i.e.* if an object in the median plane were seen double, but becomes single if moved to the left, then it can be seen singly in the median plane by rotating the head to the right. Similarly inclining the head backwards or forwards has the same effect as lowering or raising the eyes respectively.

PARALYSIS OF THE MOTOR MUSCLES.

Affected Muscle and Nerve Supply.		Direction of Normal Action of the Muscle, also of the False Image and that in which Movement is Limited.	Nature of the—(a) Strabismus, (b) Diplopia.	The Affected Eye is deviated—	The Head is Inclined, and the Diplopia increases on looking towards the—	Position and Inclination of the Projected Images in Space. Right and Left indicate the Images pertaining to those Eyes respectively.	
External rectus (6th nerve)	Right	Right	(a) Convergent (b) Uncrossed	Left	Right (Also at greater distances)	| Left |	| Right |
	Left	Left		Right	Left		
Internal rectus (3rd nerve)	Right	Left	(a) Divergent (b) Crossed	Right	Left (Also at shorter distances)	| Right |	| Left |
	Left	Right		Left	Right		
Superior rectus (3rd nerve)	Right	Left and up	(a) Divergent and downwards (b) Crossed with the false image above	Right and down	Right and up	\\ Right |	| Left /
	Left	Right and up		Left and down	Left and up		
Inferior rectus (3rd nerve)	Right	Left and down	(a) Divergent and upwards (b) Crossed with the false image below	Right and up	Right and down	/ Right |	| Left \\
	Left	Right and down		Left and up	Left and down		
Superior oblique (4th nerve)	Right	Right and down	(a) Convergent and upwards (b) Uncrossed with the false image below	Left and up	Left and down	| Left /	\\ Right |
	Left	Left and down		Right and up	Right and down		
Inferior oblique (3rd nerve)	Right	Right and up	(a) Convergent and downwards (b) Uncrossed with the false image above	Left and down	Left and up	| Left \\	/ Right |
	Left	Left and up		Right and down	Right and up		
Complete paralysis of the 3rd nerve involves all the muscles (except the external rectus and superior oblique); also the levator palpebræ, the ciliary and the sphincter of the iris.			The upper lid droops, the pupil is dilated, the Ac. is absent, the eye projects. The strabismus is divergent and downwards, the diplopia is crossed with the false image above. Movements are limited in all directions except out and down.		Right eye Left eye	/ Right |	| Left \\

Tests for Binocular Vision.—It is by no means easy to determine whether there is alternating or simultaneous binocular vision. If the subject has never enjoyed fusion he cannot assist, and although he sees with both eyes, the vision may be alternating. The following tests can be employed—

Bar Test.—Some print is read by the subject, and a bar (Fig. 72) is placed in the median line between his eyes and the print. The bar is a strip of metal about 1 cm. in diameter and bent at each end to a right angle. This is laid vertically across the page and the subject holds his head 33 cm. or 40 cm. away. If the subject can, without halting, continue to read the whole of a few lines he has simultaneously binocular vision. If one eye only sees, that part of the print on the same side as the non-seeing eye will be blocked out by the bar. This is the most simple, rapid and easily applied binocular vision test. In place of the special bar, any strip of wood or rule serves the same purpose. If the rule used is wide it must be held fairly close to the eyes, and whatever width it is, care must be taken that it be held sufficiently close so as not to occlude the same print from both eyes. A pencil placed vertical to a book serves very well.

The Red-green Test, commonly called the *friend* test, consists of the word friend printed alternately in red and green letters on a black card, or formed of transparent letters on glass, the rest of the latter being opaque. If, say, before the right eye a red glass be placed, the green letters cannot be seen, while the red letters cannot be distinguished by the left eye before which a green glass is placed. With these glasses up, if the subject reads the complete word "friend" both eyes see; if he reads "red," only the right eye sees; if he reads "fin" only the left eye sees. It is an excellent test for learning whether vision is alternating, for then the subject would alternately read "red" and "fin."

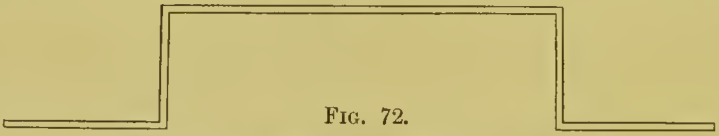


FIG. 72.

Prism Test.—This is objective and exceedingly valuable. If a seeing eye views an object through a prism, it must rotate towards the edge of the prism in order that the image shall fall on the macula. The subject is directed to view a distant object and a prism of 4° base out is placed in front of the one eye which, if it turns towards the edge, must be a seeing eye. The other is similarly treated and, if both respond, there is obviously binocular vision. The eye must be regarded *behind* the prism and not through it; otherwise the observer may mistake the deviation caused by his looking through the prism at the observed eye, for an actual deviation of the latter. This test is infallible for proving *binocular*, but not *simultaneous* vision. If, when a prism is placed before an eye, double vision results, there must be simultaneous binocular vision, and it is as simple as any test for this purpose.

The Maddox Rod Test.—The rod or groove is placed in front of the good eye and if both streak and flame are seen at the same time, there must be binocular vision, but it does not prove that fusion is possible. This test may be regarded as the last appeal for deciding, when there is squint, whether the vision of one eye is suppressed or not; if it is suppressed to an extent such that a flame in a darkened room cannot be seen, that eye must be considered absolutely blind.

The diaphragm test of Bishop Harman and Worth's amblyoscope also serve for testing the presence of binocular vision.

Ocular Exercises.

Muscle Training.—If harmony between Ac. and Con. be restored by lenses, the ordinary exercise of Con. and lateral movements of the eyes serve sufficiently well to strengthen weakened muscular functions or to restore relative equality of power between antagonistic muscles. This is natural training, special training being called for only if the former fails.

Muscle training, frequently called *orthoptic exercise*, is a class of work which depends, far more than sight testing, on the personality of the optician. It may be successful in the hands of one, and not so in the hands of another, given the same case to work upon; again, while successful with one subject, it may not be so with others. Only low insufficiencies are likely to be benefited, and further, it is not often the case that a customer has the patience to continue a treatment, for a sufficiently lengthy period, for the effect to be beneficial.

The strength of weakened muscles, or weakened functions of muscles, can be increased by exercises designed for the purpose or, at least in the case of the horizontal muscles, exercise produces an increased positive or negative relative Con. or both. It is found that the prism power overcome by the various muscles may be considerably augmented if the power be gradually increased by means of some form of rotary prism, the test object being a candle flame, or small white disc, a bright button, or the knob of a door, at 6 metres. For near distances the rod and ball, or a small letter may be employed in the same form of exercise.

Various methods of muscle exercises have been, and are, recommended by the few authorities who deal with this subject, but there does not seem to be agreement as to the best method, if indeed there be any such one. Natural gymnastic exercises, as in the alternate contraction methods, generally prove the most satisfactory, but probably the best results are obtained by utilizing with judgment all the three classes mentioned in the following articles, the possible variations being numerous.

In all cases the refractive error is corrected, the lenses worn during the exercises, and the prisms are *adverse*, *i.e.* base towards the more efficient muscles, thus causing increased action of the defective muscles. Therefore it need not be repeated in each case that, for exercising the internal recti, the prisms are base out, and for the external recti, base in; for the right superior, or left inferior the right prism is base down or (and) the left base up; for the other vertical recti they are reversed. It is always advisable to use, in these exercises, pairs of prisms, if they are at all strong, say, over 2△ each, but with less total power than 4△, a single prism is permissible. The prism power mentioned in the text is the total, and should then be half that amount for each eye, if it is divided.

So much discretion is needed by the optician that merely the briefest outlines of some methods are given, and the extent, or duration, or frequency, of the exercise must be left to his judgment. The increase of prism power, of duration of exercise, and of frequency are obtained little by little—from time to time—as the weak muscles become more efficient.

Sustained Contraction Exercises.—In these, adverse prisms are employed continuously for defined periods, thus causing increased action of the weaker muscles.

(*a*) Nearly the highest prisms that can be overcome are first used and their power increased little by little so long as diplopia does not occur. They are used daily for a minute or so, 2 or 3 times, with intervals of rest, for distance only.

(*b*) Weak adverse prisms, 1△ to 4△, are given to be worn frequently every day for short periods. The time is gradually increased until they can be overcome without discomfort for an hour, when they should be used for reading, at first for a few minutes only, then for increasingly long periods.

(*c*) The prisms employed are, for the internal recti, 2△ increasing to 12△; for the external 1△ increasing to 6△. They should be worn for distant vision twice daily, for, say, 5 minutes and the time gradually increased to 15 minutes. After having been used some days for distance only, they should be used also for reading twice daily for, say, 5 minutes and the time gradually increased to an hour. Distance and near work should be at first alternate, then a little of both, until both can be achieved without fatigue. Here both time and power are gradually increased, but in (*b*) only the time.

Varied Contraction Exercises.—Here the action of the muscles to be exercised is constantly varied by one of the following methods:

(*d*) A variable prism first set at zero power is turned on and gradually increased to that extent which the inefficient muscles can overcome without diplopia ensuing. A few seconds interval is given, in order to obtain complete fusion of the images, before each increase of power is given. There are various forms of rotary prisms, but probably the prism verger of Dr. Maddox, previously described, is the best.

(*e*) The internal recti can be exercised by slowly approaching a pencil towards the eyes and as slowly removing it to 40 or 50 cm. This exercises the internal recti without using prisms, by varying the natural call on the muscles as the distance of the object is altered. If used with prisms it can be employed for the external as well, when the prism effect is varied by the change of the object distance; this method is useless, however, if the accommodation is weak. A variation in this exercise is to alternate the approach exercise with vision of a distant object; thus distant vision, then vision at arm's length, approach to the near point, distance again and so on. A better test object is a small black dot, or a thin black line on white ground.

(*f*) Change of distance of the object by change of distance of the person viewing it, adverse prisms being used. The best way is to view the object from a near position, and then to move slowly away from it, returning towards it again and so on.

(*g*) Alteration in the distance between two objects, whose images must be fused, as by the amblyoscope, or adjustable stereoscope (vide *the Stereoscope and Amblyoscope* below). The prism power, if any, is a fixed quantity and divergence or convergence is gradually increased by alteration of the distance between the two pictures, a slight pause being made between the alterations so that fusion of the images may take place. This exercise is, of course, suitable only for the horizontal recti and does not differ materially from the exercises for fusion mentioned later.

Alternate Contraction Exercises.—In these, alternate contraction and relaxation of the deficient muscles are obtained by alternate use and non-use of adverse prisms.

(*h*) A power which is somewhat weaker than the strongest that can be overcome is employed; its power is increased slightly, and then again reduced, by alternately adding to it, and removing, an additional prism, the strength of the first prism, and that of the additional prism, being gradually augmented. The duration of the exercise is, at the commencement, 2 to 3 minutes daily, the time to be increased as the muscles become stronger.

(*i*) A distant flame, or white disc, is viewed *alternately without and through* a pair of weak adverse prisms, each for a short period. This is on the lines of Dr. Savage's rhythmic exercises, the strength of the prisms and the time employed being gradually increased. The object is viewed first without the prisms for, say, 3 increasing to 5 seconds, and then with the prisms for the same period. In the latter case, additional action of the defective muscles is obtained, and relaxation of this additional action results from removal of the prisms (say, by lifting them upwards). The exercise should be practised two or three times a day for about 2 minutes, gradually increasing to 15.

The prismatic power for esophoria is 2^{Δ} increasing to 12^{Δ}; for exophoria 1^{Δ} increasing to 4^{Δ}; for hyperophoria $1/2^{\Delta}$ increasing to 2^{Δ}.

(*k*) A variation of this last exercise is to alternate distant vision with that of a near (reading distance) object, both of them alternately with and without the prisms, each period of fixation to last for, say, 3 seconds. Again, this can be varied by changing the distance between the eyes and the test object by approaching and receding it.

Notes on Orthoptic Exercises.—No exercises should be carried on so long as to cause fatigue of the weak muscles, or pushed to the extent of causing diplopia as the case may be. It is useless over-fatiguing already weakened muscles ; at the same time, individuality has an influence, in this connection, which does not differ greatly from that which would apply in ordinary physical culture exercises.

If the exercising prisms are weak, the exercises may be longer continued or repeated more frequently, but with strong prisms they must be short of duration and less often. For example, an exercise carried out twice a day with a 4$^\Delta$ prism for 6 minutes, could be varied by employing a weaker prism for a longer time, or more frequently. As a general rule short exercises frequently repeated are better than long ones and weak prisms give better results than strong ones. Exercising should not be suddenly dropped, but should be lessened as gradually as it was increased.

It will be seen that some exercises can be effectively made by the subject himself, but when changes of prism power are required, this can be done safely only with the aid of the optician. When exercises are done at home, early morning is preferable, anyhow not late at night. Care must be taken to show how the prisms are to be held, and they are better mounted to prevent mistakes, which may easily be made by one not understanding their effect.

Dr. Maddox recommends, instead of a number of square exercising prisms, the use of a pair of round prisms mounted in a special frame so that their inclination can be easily changed to increase either the vertical or horizontal effect.

Exercise for Cyclophoria.—Dr. Savage recommends the rotation of oblique cylindricals whose inclination is gradually increased, the object being distant and corrective lenses worn. The power of the cyls. employed vary from ·5 to 5 or 6 D., but usually are about 1·5 D. A pair of cylindricals axes vertical is placed before the eyes, and from this position both are rotated symmetrically first 15°, then 30° and finally 45°; the exercise is improved by alternating vision through the cylindricals and without them. For insufficiency of the superior oblique the rotation of + cyls. is inwards above, and of – cyls. outwards above. For insufficiency of the inferior obliques + cyls. are rotated outwards above, and – cyls. inwards above.

Exercises for Amblyopia and Fusion.—Partial binocular amblyopia should be more or less improved by the use of correcting lenses ; this is a kind of natural exercise.

To exercise one partially amblyopic eye it should be used by itself for distance, with correcting lenses, the better eye being occluded ; or it can be used in company with the better eye, the latter having its visual power reduced, by means of a smoke glass, to equal the other. After thus using the defective eye for some days, for a quarter to half an hour, two or three times daily, the following and more important exercise is given. The amblyopic eye is exercised, the other being occluded, by reading with the correcting lens the smallest possible type. This exercise should be for a few minutes at first, the time being gradually increased and the size of type decreased as the visual faculty is improved. In hypermetropic cases, a surgeon sometimes puts the better eye under atropine, thus enforcing constant use of the defective eye, or they occlude the good eye with a shade. With adults, or children of sufficient intelligence, a frame having an opaque disc for the good eye can be employed. For those other than young children, bar reading (described in the bar test) is good practice; or for the same purpose, a fairly thick pencil, or small rod held vertically between the eyes and print, may be substituted for the bar. This will force the bad eye to be used in conjunction with the other, and is practically the same as that employed for improving the sense of fusion.

Other exercises are with the stereoscope and amblyoscope referred to in the following articles.

The Stereoscope.—To exercise fusion (and divergence) a stereoscopic box may be employed without prisms but with lenses whose focal length is equal to the depth of the box. In each division a card bearing half of a letter is placed, the distance between the cards being variable. At the commencement they must be sufficiently near to each other for fusion to occur, after which gradual separation and approximation of the cards serves as a gymnastic exercise. Here there is no Ac. and the effect on the muscles is increased if the lenses be gradually lessened in strength to allow of Ac. during the exercise. Instead of moving the card, varying prism power can be obtained by altering the separation of the lenses. These stereoscopic exercises mentioned serve for exercising fusion, the test objects being parts of a letter, a face and a figure, the one a mouse and the other a trap, a bird and a cage or any combination such that only by fusion can a complete picture be obtained. In many of these exercises it is advisable to lessen the acuity of the better eye to equalize it with the worse eye. This can be done by using a smoke glass, or reduced illumination, for the one picture.

The Worth-Black Amblyoscope is an ingenious instrument for stimulating, exercising and developing the fusion faculty. It consists of two bent tubes through which two pictures are seen and fused; one set of pictures is designed specially for stimulating binocular vision, another for stimulating fusion, and the third for inducing stereoscopic impression. The distance between the pictures, as well as the intensity of illumination of each picture, can be easily varied.

Exercises with children are usually carried out by the surgeon himself or under his direction, as binocular vision and fusion, in some cases, is induced only by the most careful manipulation. Where there is convergent strabismus in children, the period of life during which an impaired fusion sense can be best remedied is between 3 and 6 years; before 3 the child is too young to become interested in pictures and after 6 or 7 the faculty is often too much depleted to be restored. Nevertheless these limitations vary with the eyes themselves, with the intelligence of the child, and with the skill of the surgeon.

Exercise for Ac.—The strongest pair of Cc. lenses that, without *excessive strain*, allows of clear vision, is alternately used and not used for viewing No. 6 type at 6 m.; the exercise may be varied by gradually approaching the type. In the former the Ac. is brought into action without Con.; in the latter exercise it is assisted by Con.

CHAPTER X

PRESBYOPIA

Derivation.—πρεσβος, old; ωψ, eye.

Definition.—Pr. is usually defined as that condition in which the P. P. has receded beyond 22 cm. or 9 in., *i.e.* it is presumed to exist when the Amp. of Ac. is below 4·5 D. This definition, based on the recession of the P. P. to a given arbitrary fixed distance, is one that does not apply in many cases. Some people are presbyopic when the Amp. of Ac. is higher than 4·5 D., while some are not even with a much lower Amp. Pr. can be rather defined as that condition, due to age, in which, when the efforts of Ac. and Con. are equal, the amount of Ac. exerted is insufficient for clear vision at the reading distance. It can also be defined as that condition in which—on account of increased age—additional Cx. power is required for near vision.

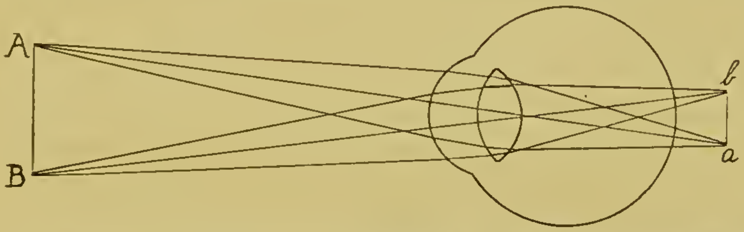


Fig. 73.—Showing the Conjugate Focus, of a Near Object, behind the Retina of a Presbyopic Eye.

The Optical Condition.—When the static refractive power of the eyes is sufficient to bring parallel rays to a focus at the retina there is not, in theory, sufficient auxiliary power for the light diverging from some near point; the focus of this divergent light is then behind the retina as shown in Fig. 73. Actually, in incipient Pr. there may be sufficient Ac. for near vision if only sufficient effort be made.

Presbyopia can be illustrated by holding a Cx. lens, at a distance equal to F, in front of a screen. Then if a source of light is brought from ∞ up to some near distance, the image is no longer sharp and, in order that it may be rendered clear, there is needed an additional power equal to the distance of the object expressed in diopters. This the presbyopic eye cannot supply wholly or in part, as the case may be, by means of accommodation.

The Natural Reading Distance.—Apart from optical or other defects which may cause print, of necessity, to be held nearer, the natural reading distance is generally that which results when the arms are bent at right angles. Consequently the reading distance depends on the height of the subject, and generally it is more distant with men than with women. An average distance of 40 cm. or 16 in. is so common that, throughout this chapter, it will be taken as the reading distance, but it must be understood that some require a lesser distance, say, 33 cm. or 13 in. and some a greater. In extreme old age the reduced V. A. necessitates a reading-point of about 25 cm. or 10 in. Therefore, in order to obviate the necessity of repeated reference to this fact, the reader must take it that when 40 cm. or 2·5 D. is referred to, the distance, in any individual case, may be greater or less.

Cause of Pr.—The cause of Pr. is lessened accommodative action due to loss of resiliency in the crystalline lens. It is possible that decreased power of the ciliary muscle also has a bearing on the condition. The hardening of the Crys. commences quite early in life, at 10 years of age or so, and perhaps earlier. We do not, however, consider this a defect until it interferes with the ability to use the eyes for continued close work, and with their easy adjustability for various near distances.

Pr. is independent of the static refractive condition and appears equally in any refractive error; nevertheless, as will be shown, H. and M. have some influence on the advent and degree of Pr., and the latter must not be confused with acquired H. arising from quite other causes. Pr. is a normal condition in that it is a natural concomitant of age; all eyes must suffer from it in the course of time.

Our knowledge of the real cause of Pr. leaves much to be desired and is mainly due to our lack of information as to the precise mechanism of Ac. Concerning the latter we merely know that the Crys. is increased in power by that action; concerning Pr. we merely know that Ac. for a given distance becomes difficult or impossible. The Helmholtz theory of Ac. seems specially weak in accounting for the difficulty in incipient Pr., whereas the Tscherning theory seems to explain it more satisfactorily.

The Age of Appearance depends upon the amount of Ac. that can be comfortably exerted for continued close work and upon the reading distance. If a person, say, 40 years of age, with an Amp. of 4·5 D. can continuously exert only half of his Ac. and reads at 40 cm. he is presbyopic ·25 D.

In practice we find, firstly, that the average Amp. of Ac. is greater than that mentioned; secondly, more than half the Amp. possessed can be freely and continuously exerted and, thirdly, the print can be held a little farther away, where the Ac. produced is sufficient for clear vision when the effort of Ac. is equal to that of Con. Therefore the average male emmetrope does not show signs of Pr. until, say, 45 or 47.

It is sometimes said that if H. or M. be present the advent of Pr. is, respectively, hastened or delayed. Now this appears true only if Pr. be regarded as that condition in which Cx. sph. power is needed for reading purposes. In this case, indeed, Pr. may exist in a very young hypermetropic child, or it may never be present, even in extreme age, where M. exceeds 2·5 D. or 3 D. If Pr. be regarded as that condition in which additional positive refracting power must be *added* to the distance correction, in order to supplement deficiency of accommodative action, then Pr. may be present at a very early age in M. and quite late in life in H.

As a matter of fact Pr. can be present even if Cx. lenses are not needed for reading, and may be absent even if they are so. The refractive errors influence the advent and the degree of Pr. only so far as they cause Ac. to be more or less active than in Em. and in so far as they affect the relationship between Ac. and Con., and to a slight extent, in high errors, owing to the change of effectivity of strong lenses in near vision.

H. of ordinary degree generally causes Ac. to be active so that the Amp. at a given age, may be greater than in Em. M. tends to render Ac. inactive and the Amp. is generally smaller than in Em. at a given age. In this way H. retards the advent of Pr. while M. hastens it and the degree of Pr., at any age, would be smaller in H. and larger in M. than in Em. A great factor in the advent and degree of Pr. is the condition of balance between the internal and external recti. When Eso. is present Con. is easy and requires little effort for fixation at the reading distance, and this is harmoniously accompanied by a small effort of Ac.; in this case Pr. appears early. When Exo. exists, the effort of Con. and therefore of Ac., is great, and Pr. appears late. Now with H. the usual muscular condition is that of Eso., and for this reason H. causes Pr. to appear early in life. In M. the usual muscular condition is that of Exo. and, in consequence, Pr. makes its presence felt late. Since these conditions are opposed to each other it is safer to consider that the static optical defects of the eye have little influence on Pr. except that, in the more unusual conditions of exophoric H., the advent and increase of Pr. is delayed and in esophoric M. it is hastened. (See also p. 275.)

Apart from the before-mentioned factors, Pr. appears earlier among Orientals and coloured races who develop and reach maturity sooner in life. There is even a marked difference between the southern and northern inhabitants of Europe and America in this connection, the latter becoming Pr. later than the former. Also the distance of reading plays a part, for the one who reads at a shorter distance becomes Pr. sooner than one who reads at a greater distance. Thus women usually become Pr. sooner than men, and short sooner than tall people. In addition the visual acuity, if poor, necessitates a close reading distance and apparently hastens Pr.

Symptoms.—When Pr. commences the first symptom is the desire to move reading matter to a greater distance than previously. By so doing a position is sought at which the Ac. exerted does not exceed, say, one-half of the total possessed. Thus if the Amp. = 4 D., at 40 cm. the 2·5 D. required exceeds one-half, whereas at 50 cm. the 2 D. required does not. The presbyope who has difficulty with reading may thus be still able to write or do other work with comfort, because it is done at a greater distance. The symptom which soon follows is that of inability to see small objects, as fine print, the eye of a needle, &c., because these must be held nearer in order to be seen at all. Again the eyes become tired when reading and after some time the print runs together or becomes indistinct. The cause of these symptoms is that, while the supplementary effort of Ac. made in order that Ac. may equal Con. can be effected for a time, the eyes soon tire, or the effort of Ac. cannot be maintained, so that the image of the print previously sharp at the retina, becomes blurred. Relief from the tiredness and blurring is sought by looking at a distance and frequently by rubbing the eyes.

All those symptoms are more noticed at night than in daylight. Firstly one's day occupation is likely to consist of work done at a greater distance; secondly, the eyes are fresher early in the day so that the extra accommodative effort can be more easily effected without the ciliary so soon becoming tired; thirdly, artificial light, being coloured, causes less contrast between white and black so that print has to be held nearer in order to be seen; fourthly, the cause of the evening troubles of presbyopia is often the redness of artificial light, because red needs more Ac. in order to focus at the retina than does any other spectrum colour or white. The distance at which print can be held, in order to be read, is, of course, limited, by its size and also by the difficulty of holding a book or paper at an inconveniently great distance.

The presbyope seeks good light, because by so doing, he is enabled to hold print farther away; again a perfectly sharp retinal image is not necessary in order that print be recognized; further, the more intense the illumination the smaller do the pupils become. The latter is found in an exaggerated form when the presbyope places the light between himself and the print. Here the nearness of the light increases the illumination to a great extent and, at the same time, the pupils become very contracted, whereby the retinal circles of confusion are much reduced. Later on fine print cannot be read without lenses at any distance, no matter how bright the illumination or how great an effort of Ac. be made.

The Proportion of Ac. Available.—Generally, a person can use, without undue strain, one-half to two-thirds of the total Amp. possessed and if the demand on the Ac. does not exceed this, reading is usually effected without discomfort. No one can exert continuously the full force of a muscle and, although the ciliary exceeds most others in this connection, there is a limit which is reached, in the average individual, when of the total force available there is *left in reserve* less than a half or a third as the case may be. Some require a greater and others only a smaller reserve.

The Determination of Pr.—Pr. is determined if ordinary-sized type, say No. 3, is read better at a greater distance than 40 cm. than at the latter point itself. It is determined, if more advanced, when fine print cannot be read at the usual distance notwithstanding that distant vision is corrected, this latter being always first done. Further, the determination can be made only when both eyes are used together, as the presence or absence of Pr. depends largely on the effort of Con. made for fixation at the reading distance.

The Remedy consists of those + sph. lenses which represent the difference between the amount of Ac. produced and the amount needed for seeing at the reading distance when Ac. and Con. are equally innervated. Thus if when Con. = 2·5 M. A. the Ac. = 1·5 D., the presbyopic correction required is + 1 D.

Asthenopia is caused by want of harmony between Ac. and Con. and presbyopia affords a good proof of the fact that *inequality of effort* between these functions is the cause of asthenopia rather than either the individual degrees of effort or the want of harmony between the *quantity* of each that is exerted. An Em., age 35, reading at 33 cm. exerts 3 M. A. of Con. and 3 D. of Ac. and there is no Asth. because the efforts of Ac. and Con. are equal. Ten years later this same Em., reading at the same distance, exerts exactly the same quantity of each function but there is Asth. because, in order that the Ac. may correspond in amount to Con., a greater *effort* of Ac. is called for. Hence Asth. results in Pr. because the effort of Ac. is greater than that of Con. in order to produce a quantity of the former function equal to that of the latter. No Asth. results in Pr. when the Ac. is so depleted that, no matter how great an effort be made, clear near vision is impossible. In this case the effort is abandoned.

The Practical Determination of Pr.—After each eye has been corrected by the distance test and so made practically Em., both eyes are directed to the hand types, so that Con. for the reading distance is brought into action. The subject is directed to read ordinary type, say, No. 3 at his natural reading distance as already defined. The hand card is then moved slowly away and if reading is then better, *i.e.*, if the types become clearer—the condition of Pr. is determined. If the reading is not improved by thus receding it, Pr. is non-existent and no addition is required to be made to the distance glasses. If the Pr. is of higher degree, as when the age is, say, 50 or more No. 3 type will not be legible at the natural distance ; it is obvious that Pr. is present and needs no actual determination, although this results if additional + power renders it possible to read fine print.

The Practical Correction.—The correction is made binocularly because—with rare exceptions as in antimetropia—the depletion of the Ac. is the same in both eyes. Also it is impossible to determine the deficiency in the Ac. unless the Con. is in action for the distance at which close work has to be done. Pr. having been determined as stated in the last article, the subject is asked to indicate the smallest possible types that he can just read. To these types a number is appended and indicates the *approximate* power of the needed lenses with which, if added to the distance lenses already in the frame, No. 1 type, *i.e.* the smallest—is legible. Attention is then again drawn to No. 3 types and the hand card is moved farther away from, and nearer to, the eyes than the natural reading distance. If No. 3 is read better when farther away, the lenses are too weak; if it is read better, when nearer to the eyes, they are too strong. In the first case the lenses have to be slightly increased in strength, in the second case they must be reduced.

The proper correction for any case of Pr. is that pair of Cx. lenses which, added to the distance glasses, cause vision of ordinary sized types (Nos. 3 and 4) to be better at the natural reading distance than either nearer or farther away. With these lenses there is a certain range—within and beyond the reading distance—within which the presbyope can see by exerting more or less of what Ac. he possesses.

It is said by some that the amount of Pr. is not always the same in the two eyes, but apart from antimetropia or high anisometropia, the writer has not encountered any such cases.

Reason for the Test.—If a person when he converges for a given distance naturally exerts a certain amount of Ac. it follows that any given power of Cx. lenses can be exactly suited for one distance only. Suppose the total Amp. be 3 D. and of this 1·5 D. accompanies convergence for 40 cm.; the presbyopic correction is then + 1 D. With the + 1 D. he sees better and more comfortably at 40 cm. than either nearer or farther. If the print be removed to 50 cm. the Ac. which naturally accompanies 2 M. A. Con. is more than 1 D. so that the glasses are too strong. At some nearer distance, say 33 cm., the Ac. associated with 3 M. A. Con. is less than 2 D. and the glasses are too weak. At any distance other than 40 cm. the lenses do not supply that power with which the efforts of Ac. and Con. are equal. Suppose in this case + ·75 D. lenses were first given; then vision would be more comfortable farther away than 40 cm.; if + 1·25 D. were put up, it would be better at a nearer point.

Glasses for Different Distances.—From the last article it will be seen that an accurate correction of Pr. for any distance is represented by only one dioptric power. If we went on the hypothesis that a person can use half his Ac. for *sustained* close work he would require with an Amp. of, say, 3 D., $3 - 1{\cdot}5 = 1{\cdot}5$ D. for 33 cm., $2{\cdot}5 - 1{\cdot}5 = +1{\cdot}0$ D. for 40 cm., $2 - 1{\cdot}5 = +{\cdot}5$ D. for 50 cm. and $1{\cdot}5 - 1{\cdot}5 = 0$ for 66 cm. In this calculation the corrections for the different distances differ as their dioptric differences, but actually it is far more often the case that less reserve is needed as the distance of vision is nearer and Con. therefore greater.

The Range of Vision in Corrected Pr.—When Pr. is corrected the eyes are made artificially myopic by the Cx. lenses given and the range of Ac. is limited as in M. Suppose an emmetrope, or an ametrope made emmetropic by lenses, has 2 D. Amp. of Ac.; his P. R. is at ∞ and his P.P. at 50 cm. To correct the Pr. suppose + 1·5 D. lenses be given for 40 cm.; then the range of vision is between the artificial P. R., which is at $100/1{\cdot}5 = 66$ cm. and the P. P., which is at $100/(2 + 1{\cdot}5) = 28$ cm. With the presbyopic correction given for 40 cm. he can see as far away as 66 cm. by relaxing all, and as near as 28 cm. by exerting all his Ac.

Expressed in diopters, the P. R. is represented by the correcting Cx. lens and the P. P. by the Amp. of Ac. + the Cx. lens; in this case the P. R. = 1·5 D., the P. P. $= 2 + 1{\cdot}5 = 3{\cdot}5$ D. and the Amp. $= P - R = 3{\cdot}5 - 1{\cdot}5 = 2$ D., the same as without the lens.

When the Amp. is greatly depleted, the range of Ac. with the presbyopic correction is very restricted. When the Pr. is incipient the range is fairly great and becomes smaller as natural Ac. is replaced by the artificial Ac. of a Cx. lens until, when it is all artificial the Amp. of Ac. being zero, the P. P. and the P. R. coincide and the presbyope can see clearly at one distance only with his corrective lenses.

Estimated Corrections.—If the proportion of the total Ac. that can be exerted be taken as one-half, and the Amp. of Ac. at certain ages to be as given below, we can calculate the presbyopic corrections in Em. or in corrected Am., for certain distances, as follows:—

$$D_P = D_R - A/2.$$

Where D_P is the presbyopic correction in diopters, D_R the dioptric expression of the reading distances, and A. the Amp. of Ac. possessed at the given age.

AGE.	40.	42½.	45.	47½.	50.	52½.	55.	60.	65.	70.	75.
Amp. of Ac. in diopters	4·5	4	3·5	3	2·5	2	1·5	1	·5	·25	0
P. P. in cm. without reading glasses	22	25	28	33	40	50	66	100	200	400	∞
Reading glasses in diopters for 40 cm.	·25	·5	·75	1	1·25	1·5	1·75	2	2·25	2·5	2·5
Reading glasses for 33 cm.	·75	1	1·25	1·5	1·75	2	2·25	2·5	2·75	3	3

It will be noticed that (*a*) at 40 years of age, when Pr. first starts, the correction needed is only ·25 D. for reading at 40 cm. (*b*) The correction increases normally by ·25 D. for every 2 1/2 years and later for every 5 years. (*c*) For 33 cm. (3 D.) the correction required is always ·5 D. more than for 40 cm. (2·5 D.), and varies similarly for other distances. (*d*) The total correction never exceeds 2·5 D. for 40 cm., or 3 D. for 33 cm. and similarly, for other distances, *e.g.* it would never exceed 1 D. for 100 cm. 2 D. for 50 cm., or 4 D. for 25 cm.

The power of the lenses required depends on (*a*) the distance for which glasses are needed, (*b*) the Amp. of Ac. possessed, which may differ from those above given, it being generally greater, (*c*) the effort of Con. made for fixation.

The following are some examples :

Pr. with Em.—Suppose the age to be 52, the reading distance 40 Cm and half the amplitude available for continued close work. We then have for the presbyopic lenses—

$$2{\cdot}5 - 2/2 = +1{\cdot}5 \text{ D.}$$

A clergyman, age 65, needs a pair of glasses for reading his notes in the pulpit, his working distance being, say, 1 m. the lenses he requires are—

$$1 - {\cdot}5/2 = +{\cdot}75 \text{ D.}$$

Pr. with H.—The strength of the presbyopic lenses depends on the same conditions as in Em. but they are always as much stronger as the degree of H. Thus suppose the distance correction is O. D. + 2 D. and O. S. + 1·5 D. and lenses are required for reading music at 66 cm. by a person aged 48 who must keep 2/3 of his Amp. in reserve. Then the addition power is—

$$1{\cdot}5 - 3/3 = +{\cdot}5 \text{ D.}$$

so that the total reading lenses are—

$$\text{O. D.} + 2 + {\cdot}5 = +2{\cdot}5 \text{ D. and O. S.} + 1{\cdot}5 + {\cdot}5 = +2 \text{ D.}$$

Pr. with M.—Again the same factors govern the selection of the reading lenses ; if Cx. they are as much weaker than in Em. as the degree of M., and if the latter exceeds the Pr. the lenses for reading are Cc. As an example, suppose the myope age 45 uses O. D. – 5 D. and O. S. – ·75 D., and requires glasses for seeing clearly at 25 cm. with half the Amp. in reserve. Then calculation would give us—

$$4 - 3{\cdot}5/2 = +2{\cdot}25 \text{ D.}$$

added to the distance glasses, making those for reading—

$$\text{O. D.} - 5 + 2{\cdot}25 = -2{\cdot}75 \text{ D., O. S.} - {\cdot}75 + 2{\cdot}25 = +1{\cdot}50 \text{ D.}$$

The myope makes up for his deficient Ac. by his excessive static refraction and although he may not need Cx. lenses for reading, nevertheless he is presbyopic if he cannot accommodate owing to age. A myopia of 5 D. or 6 D. is the lowest in which there can never be needed Cx. lenses for reading if the acquired H. of an old eye be taken into consideration.

Pr. with As.—The cyls. selected for distance are to be taken as the same as those required for close work, *i.e.* the degree of As. does not change.

Thus suppose O. D. − ·25 S. ⬭ − 2 C. Ax. 40°; O. S. +1 C. Ax. 70° be the distance lenses of a clerk age 55 who wishes to see his books at 50 cm., a reserve of 1/3 the Amp. being required. The presbyopic addition is—

2 − 2/3 of 1·5 = +1 D.,

which, combined with the distance lenses gives, as the total reading correction—

O.D. + ·75 S. ⬭ − 2 C. Ax. 40°; O.S. + 1·0 S. ⬭ + 1·0 C. Ax. 70°.

In some cases, old people, who have never used cylindrical correction, see better for close work without it and prefer sphs. only.

Points on Correcting Pr.—It is probable that the non-use of Cx. lenses, when Pr. is incipient, tends to the depletion of Ac. more than would be the case if they were employed, but over-correction, still more probably, has a similar effect. The use of the proper lenses and their gradual and normal increase of strength every few years, or when necessary, seems to keep Ac. active to an advanced age.

The optician should always be on his guard to note either (*a*) an apparent abnormal increase of Pr. or a high degree for the age (vide *Glaucoma*), or (*b*) an apparent sudden decrease of Pr. (vide *Cataract*).

The reading glasses should be centred for the eyes when converged for the reading point; they should not be decentred to relieve Con. because, by so doing, the efforts of Ac. and Con. are not harmonized. Any idea that Con. should be relieved in Pr. arises from a very common confusion between effort and effect. Only in exophoria may such decentering be required, the necessity arising from the muscular condition and not from the Pr.

To see near and distant objects, a pantoscopic frame is needed in Em. or low Am., or bifocals in high Am. where, without lenses, distant vision is impaired or painful. Neither of these styles are to be recommended for moving about as, with them, the ground cannot be clearly seen—an uncomfortable and even dangerous condition especially when the glasses are first used. For frames generally needed in Pr. see Chapter XXII.

The lenses for Pr. unlike those for Am. need not be placed as near as possible to the eyes; if they are at 25 mm. for their best position, the range of artificial Ac. can be increased by moving them nearer or farther away. This may be useful in cases where there is very little or no Ac. at all.

CHAPTER XI

SPASM OF ACCOMMODATION AND ASTHENOPIA

Spasm of Accommodation

THIS term is applied to an involuntary accommodative action, or cramp of the ciliary muscle, whereby the refraction of the eye is increased beyond what is required for clear vision. It is a defect of youth, and rarely met with after 30 years of age ; it may occur in any refractive condition, but low H. is that in which it is usually found. If, for example in H. 1 D., there is constantly exerted 1·5 D. or 2 D. of Ac. for distance, the eye appears to be myopic to the extent of the surplus ·5 D. or 1 D. as the case may be. Some authorities use the term exclusively in this connection while others apply it, also, to cases where the H., although not simulating M., is unduly latent. Cramp of the ciliary sometimes, but rarely, occurs in Em. but it is not infrequent in M., and causes the latter condition to appear of higher degree than it really is.

The cause of **spasm of accommodation** is chiefly uncorrected As. The subject, being unable to secure a sharp retinal focus for any distance, naturally endeavours to counteract the effect of the As. by bringing the object closer to the eyes in order to secure a larger retinal image, with the result that excessive Ac. is exerted and the action becomes habitual. In this case, correction of the As., by removing the cause, will generally prove a remedy for the spasm and all its attendant troubles. Spasm may be caused artificially by a drug such as eserine and it may be traumatic, *i.e.*, due to a blow or it may be the result of a functional or organic disorder, as inflammation of the ciliary body.

Commonly spasm is characterized by a feeling of constriction in the eyes, by general discomfort and, in fact by those symptoms accompanying accommodative and reflex asthenopia (*q.v.*).

It is termed *tonic* if the excessive Ac. is always in action and *clonic* when it comes into play only for near work.

Spasm of Ac. is sometimes accompanied by myosis or spasm of the *sphincter iridis*, the pupils being abnormally small and irresponsive to light; in other cases they are abnormally large, and even with normal pupils, the condition may be induced by excessive light.

Seamstresses, students, clerks, etc. who work by unscreened lamps placed close to, and in front of, the eyes are especially susceptible to spasm, and although, in the majority of cases, there are other influencing factors the effect of too much direct light may be the sole cause. In any event faulty lighting is always inclined to aggravate asthenopia and therefore inquiries should be made, in all cases of spasm, into the nature and position of the illumination generally used, and advice tendered accordingly.

Hypermetropia simulating Myopia is the condition that must be chiefly considered from an optical point of view, and because it is the one to which reference is generally made in connection with spasm. Now in *true* M. of low degree—even with moderate As.—there is usually very good near V. and a noticeable absence of headache and pain; consequently there should be no difficulty in distinguishing between true M. of low degree and H. stimulating that condition. Further, the power of the Cc. lens required to raise vision to the normal is far greater than it would be in true M. Thus if V. = 6/9 a – ·5 D. ought to make it normal whereas in spasm much more power would be required to effect this improvement in sight. The lenses themselves, as they are put up, seem to induce still further Ac. which is already in an unsteady condition, so that the types are read slowly and with hesitation.

The position of the P. P. will generally be found to be inconsistent with the apparent refractive condition and age. Thus if the latter be 20 and there is an *apparent* M. of 1 D. the near point should be well within 10 D.; if it be found beyond 10 D., H. should be suspected. It is useful to employ the far-point method of determining the refractive condition in these suspected cases of false M.; working the carrier gradually away from the eyes, any variation in the position of the apparent P. R. indicates spasmodic action of the ciliary almost as certainly as variable vision referred to later. The apparent Amp. of Ac., obtained from the apparent near and far points, also assist materially in arriving at a diagnosis of the case.

Other Conditions.—Since spasm can occur in M. of low degree it should always be suspected, especially if there be asthenopia and a low degree of As.; it is almost as likely to be present in M. as is a latent error in H. and, as discussed under *classification*, is a question of degree.

It is practically impossible in a treatise to differentiate between latent H. which does, and that which does not, require manifesting and correcting; but if asthenopic conditions are present when H. is all latent, or notwithstanding correction of the manifest H., the condition should be treated as if it were spasm of Ac. as defined. Most of the safeguards and tests mentioned in the last article serve, with the natural modifications, for the two conditions just referred to.

Variable Vision is the most characteristic symptom of all in spasm of Ac., and one which serves not only when H. stimulates M. but also when there is true M. If with or without any lens, the degree of vision varies as one looks at the test types, it is a positive indication that Ac. is spasmodic;

that is to say V. may be 6/12 and slowly improve to 6/9 or deteriorate to 6/18. Often with no spherical, or a weak Cx. or an apparently under-correcting Cc., it is merely necessary to tell the subject to read successively smaller types for him to do it, provided that the As. has been corrected.

The Optical Treatment of Spasm consists of (1) Carefully and *fully* correcting any As. present; low power cyls. have sometimes quite an astonishing effect in relieving asthenopia and spasm. (2) Slightly over-correcting manifest H., or well under-correcting apparent M., and giving no Cc. spherical at all if the latter be of low degree.

Some cases can only be treated successfully under a cycloplegic, and the glasses first used while the ciliary muscle is completely or partially paralyzed. Notwithstanding such optical correction as can be given without drugs, even adults may not obtain relief unless and until they have been treated with atropine for some time.

If there is spasmodic Ac. in H., which is a source of pain, and concave lenses are given, it goes without saying that the trouble is aggravated. Still worse is the fitting of Cc. lenses too strong in a case of M. as they may, in addition, bring about an increase in the true degree of M.

Classification.—Except in high M. and extreme old age, there is always some unrelaxable accommodative action due to natural activity of the ciliary muscle. A young eye which is emmetropic under cycloplegia has low M. of from ·5 D. to 1 D., in ordinary circumstances and H. is always partly latent in young people. Therefore spasm, if the term may be so used, is natural up to a certain point but becomes unnatural when accompanied by painful symptoms. If we apply the term spasm of Ac. to latent H., it is, of course, of the *tonic* class.

Very often the term is used where, owing to the Ac. being active, a faulty estimation of the refractive condition is made.

In fact, so far as the optician is concerned, spasm may be divided into two classes. The first is that condition where cycloplegia is necessary, it being impossible, under ordinary conditions, to determine the glasses that will relieve the asthenopia. The second is the condition where the Ac. gives way under a proper test, and includes those cases where, owing to faulty testing, H. has been previously under-corrected, M. over-corrected and As. badly corrected or not corrected at all. This second class can effectively be treated by the optician.

Spasm Caused by Convergence.—There is further a type of spasm which differs from that already described, in its origin and perhaps treatment. When the efforts are equal in binocular fixation, the Ac. may be in excess of what is needed for clear vision owing to exophoria, or when the Ac. is adjusted for, say, 33 cm. a considerable supplementary Con. effort is required, during which Ac. must be suppressed to retain clear vision. In consequence there is muscular asthenopia, which finds relief if extra Ac.

is permitted as when hypcropes or emmetropes wear Cc. lenses, and myopes those which over-correct the defect. There are many cases of spasm of Ac. thus induced by deficient initial Con., or by excessive mobility of the accommodative apparatus when accommodative Con. takes place, and the remedy is to harmonize these functions.

In a work on visual optics it is difficult to assign the proper position for spasm of Ac., it being a symptom of other conditions rather than a specific defect. It is so closely connected with asthenopia that a full description of the two would involve much repetition.

Asthenopia

Derivation.—α, without; σθενος, strength; ωψ, eye.

The Condition of Asthenopia is that of weak, uncomfortable, painful or irritable sight, but the term is often employed to include those conditions which accompany it, as ocular headaches, neuralgia, photophobia, fatigue, dimness of vision and inability to use the eyes continuously; it generally points to muscular strain, which is the more likely to occur as V. is acute in ametropia. In fact refractive errors almost may be divided into those with bad sight and no pain, and those with good sight but with pain. As previously stated, under the various headings, those optical errors which are corrigible by muscular effort, as low degrees of As., H., Aniso., and Hetero., are more likely to be the cause of Asth. than high degrees which no amount of muscular exertion can correct, and in which the effort is consequently not made.

Asth. is generally more severe at night when the eyes are tired and the luminant is artificial and coloured but, sometimes, irritable conditions are especially noticeable on awakening in the morning. It is more pronounced and more common among those who use their eyes continuously for close work such as clerks, students or seamstresses and, although the asthenopia may be due to optical causes, it may be augmented or induced by those assigned to nervous or reflex Asth.

Classification of Asth.—Asthenopia is usually divided into (*a*) Accommotive, (*b*) Muscular, (*c*) Nervous or Reflex. A more useful classification is (1) Accommodative-Convergence, (2) Anisometropic, (3) Astigmatic, (4) Presbyopic, (5) Hyperphoric and Cyclophoric, (6) Nervous or Reflex

Ac. and Con.—In clear binocular vision Asth. results if a high degree of either Ac. or Con. or of both, is required, especially if the effort to produce them is also great; it is still more likely to occur if there are unequal efforts, quite irrespective of the quantity of either function exerted, or of the refractive or muscular conditions. Asth. is termed *accommodative* or *muscular* according as the trouble lies chiefly with the one or other function; Pres., H., and esophoria cause excess of Ac., while in M. and exophoria the Con. predominates.

The cure lies in the complete or partial correction of the error of refraction. If there be H. with esophoria, the Ac. exceeds Con. and Cx. lenses of some certain power are required; if they are too weak some accommodative Asth. may still remain; if they are too strong, muscular Asth. may result because the effort of Con. would be greater than that of Ac. If in M. there is Asth. it is because the Con. exceeds Ac. With lenses too weak this may still remain, whereas if they be too strong accommodative Asth. is produced because the effort of Ac. then exceeds that of Con.

Hence the cure of this class of Asth. consists of those spherical lenses which produce harmony in the efforts of the two functions and, as a rule, they are not a full correction of the optical defect, but rather a modified one. When Eso. is present, and therefore Con. easy, the condition calls for strong Cx or weak Cc. correction; when Exo. obtains, weak Cx. and rather full Cc. correction is required. Harmony between the two functions is obtained rather by changing the demand on Ac. than by interfering with Con. That is, Asth. resulting from inequality of Ac. and Con. should be cured, if possible, by decreasing the accommodative effort with +, or increasing it with − lenses, so that it may harmonize with that of Con. Prismatic power employed to alter the Con. effort should be avoided and, indeed, is rarely needed. There are, however, certain limitations. We can reduce accommodative action up to giving full correction in H., and a correction in M. which calls for no Ac. whatever. We can cause accommodative action up to giving no correction at all in H., and by full correction in M. It is not permissible to over-correct H. or M., nor can Cx. or Cc. lenses be given to an emmetrope. No correction whatever and full correction of Am. mark the limits in curing asthenopia by spherical lenses; beyond this prismatic power may be required, since + prisms reduce, and − prisms increase Con. If therefore in Em., apart from presbyopia, the Ac. exceeds Con., or *vice versa*, the remedy must be sought in relieving prisms. The same is required if muscular Asth. results with full correction in M., or with the Cx. lenses needed for clear vision in H., when there is exophoria; also when there is esophoria with a full correction of H. or with a correction of M. such that no Ac. at all is brought into action. Relieving prisms are never strong; if the condition seems to call for high power, the remedy is to be found rather in exercises or in operation.

True Accommodative Asth. results from excessive demand on that function when the amount required is high, or the ciliary weak, and may exist quite apart from its want of harmony with Con. as, for instance, where there is only one seeing eye. Weakness of the ciliary may be of paretic origin, the result of illness, of non-use as in M., or of age as in Pres.

True Muscular Asth. is similarly due to a pure deficiency of the internal recti, or to a very close reading point necessitated by some outside cause such as a slight nebula in Em.; and, notwithstanding the co-existence of H., As., and other fertile sources of strain, the asthenopia may still be simply muscular.

Anisometropic Asth.—If in anisometropia both eyes see clearly the Ac. required by each eye is different, so that the effort made is probably also different and Asth. is caused. The remedy is to equalize the refraction of the two eyes so that unequal efforts of Ac. become unnecessary. Relief from this is frequently sought by closing one eye.

Astigmatic Asth.—In astigmatism, Asth. may result from sectional Ac. produced to correct the As. Oblique As. is more productive of Asth. than when horizontal or vertical but possibly there may be a complication of cyclophoria. The remedy is to equalize the refraction of the eye to such an extent that unequal Ac. effort becomes unnecessary; this does not, of necessity, call for full correction of the As. Relief is sometimes sought by partially closing the lids, thus confining the refracting system to practically a single meridian, or by looking obliquely through spherical lenses. Astigmatic Asth. may be caused not only by sectional Ac., but also by continuously altered efforts made to adjust two different focal distances to the retina.

Presbyopic Asth. is caused by the excessive effort necessary to accommodate for near distances in later life, when the crystalline does not respond so freely to the ciliary action. The remedy is to give those convex lenses which equalize the efforts of Ac. and Con. for the distance at which near work is to be done.

Hyperphoric Asth. is due to insufficiency of the vertical recti, and the remedy is prism power base up for the one eye and base down for the other, but a considerable degree of Hyper. (*q.v.*) may fail to cause asthenopia.

Cyclophoric Asth.—Insufficiency of the oblique muscles may be anatomical or caused by oblique As. Neither lenses nor prisms are of utility except that the true cylindrical correction, properly located as to the principal powers, removes the optical cause. Relief is sought for the asthenopia—as well as for improving the sight—by rotating the head over towards the one or other shoulder.

Nervous Asth.—Under this heading we must group the cases due to various causes such as nervous conditions, hysteria, functional disorders, poor health, disease, weakness, dental decay, over-use of the eyes, faulty iritic action, bad lighting, insanitary surroundings, poor or insufficient food, want of exercise, etc. It is *reflex* if the exciting cause is remote from the eyes, and so-called *retinal* Asth. is said to be due to actual fatigue or exhaustion of the nervous elements of the eyes, and there may be a quite alarming reduction in the visual acuity. Rest for the eyes and medical treatment for the originating cause are the remedies to be sought.

Accompanying, or as some of the symptoms of Asth., we find headaches which are termed *frontal* if felt over the brows, *occipital* if at the back and *supra-orbital* if at the top of the head. Pain near the temples is usually termed *neuralgic.* Other symptoms are redness or even an inflammatory condition of the lids and conjunctival membrane. The eyes become very sensitive to light (vide *photophobia*), wind and dust; a very small amount of grit, or a cold wind, sets up considerable lachrymation, and the eyes can sometimes be opened only with difficulty to face bright light. Erythropsia, or red sight, the cause of which is not clear, occasionally occurs, but may be due to want of endurance of some of the retinal elements or congestion of the bloodvessels; certainly in some cases the fundus and disc appear more deeply coloured than is normally the case, and the disc itself may appear slightly indistinct.

Most of the above symptoms accompany Asth. due to purely optical or muscular causes, and indeed the nervous variety is closely associated with the others. We must, however, make a class of the nervous type because we find cases of Asth. where there is no discoverable optical error, or only defects that fail to account for the symptoms; yet the influence of very low errors must not be forgotten.

Photophobia (φως, light; φοβος, fear), or intolerance of light, may be due to many causes which include optical defects; albinism; continued exposure to bright natural, or artificial, light; hyperæsthesia (undue sensitiveness) of the retina the result of strain and fatigue; pupils which are abnormally large naturally or caused by iridectomy, coloboma or aniridia; want of mobility of the irides. Coloured glasses may give relief and help is derived from a suitable arrangement of the illumination, whether natural or artificial, in which work is usually done, so that no direct artificial light, or too much reflected sunlight, enters the eyes. Photophobia caused essentially by an error of refraction is generally cured by a correction of the optical condition.

Mr. Charles Prentice gives, as a cause of Asth., inharmonious action of the ciliary and iris, and indeed this seems to be a very probable cause.

The Nature of the Asth.—If there is equal H. or M. in both eyes the Asth. cannot be due to other than disturbance of the relation between Ac. and Con., unless it is muscular or accommodative owing to excessive demand. If there is slightly different H. or M. in the two eyes and both have good V. it is most probably anisometropic, but not so if there is a high degree of Aniso., or if V. is unequal, or if there is only monocular or alternating V. If there is low As., with good V., it is probably astigmatic and not so if the As. is high and V. defective. It can be presbyopic only if the age warrants. Thus the Asth. may be due to different defects but it is of importance, when treating a case, to locate the chief cause or causes so that the lenses prescribed may be the means of curing it; this is sometimes easy enough but at others the origin is obscure.

Suppose a case requiring O. D. – 1·0 S. ⬭ – ·5 C. and O. S. – 1·5 S. ⬭

– ·5 C. Here it is unlikely that the M. is the cause of the Asth. but rather the Aniso. and perhaps the As.

In a case needing for both eyes + ·5 S. ○ + ·25 C. it is improbable in a young person, that the H. is the origin of the Asth. but rather the As.

In a case where the optical correction consists of, say, O. D. + 1·0 S. ○ + ·75 C. Ax. 40°; O. S. + ·5 S. ○ + 1·0 C. A. 130° and there is 3$^{\Delta}$ of Eso. and 1·5$^{\Delta}$ of Hyper., all the divisions of Asth. may be present except the presbyopic.

If a person needs O. D. – 10 S. ○ – ·5 C. and O. S. – 11 S. with Exo of 5$^{\Delta}$ it is difficult to conceive that either As. or Aniso. can be the cause of pain; this must be due to Con. alone or to Con. and Ac.

Some indications are obtained from the subjective symptoms. Thus pain over the brow indicates undue accommodative action, pains near the temples show excessive Con. action and strain on the external recti. More pain in, or over, one eye than the other shows unequal muscular effort, but if it is referred to the eye requiring less Ac. an anisometropic origin is eliminated and As. or Hyper. suggested.

Incorrect lenses may cause Asth.; thus unequal lenses may cause anisometropic Asth.; improper Cyls. may cause astigmatic or cyclophoric Asth.; decentred lenses hyperphoric or muscular Asth.; Cc. lenses too strong, accommodative Asth. A hyperope suffering no pain without lenses is subject to the asthenopia of M. if over-corrected, and similarly a myope over-corrected is subjected to the trouble of a hyperope, and new conditions are less well tolerated than those to which one is accustomed. Pain is sometimes referred to the back of the eyes, this being doubtless due to abnormal internal muscular action which specially occurs when glasses too strong are used.

Characteristically asthenopic-looking eyes—reddish, watery and weak—do not always suffer from pain; yet they need glasses just as much as those which are painful.

CHAPTER XII

SUBJECTIVE SIGHT TESTING

THE main practical points contained in previous chapters are repeated here in summarized form.

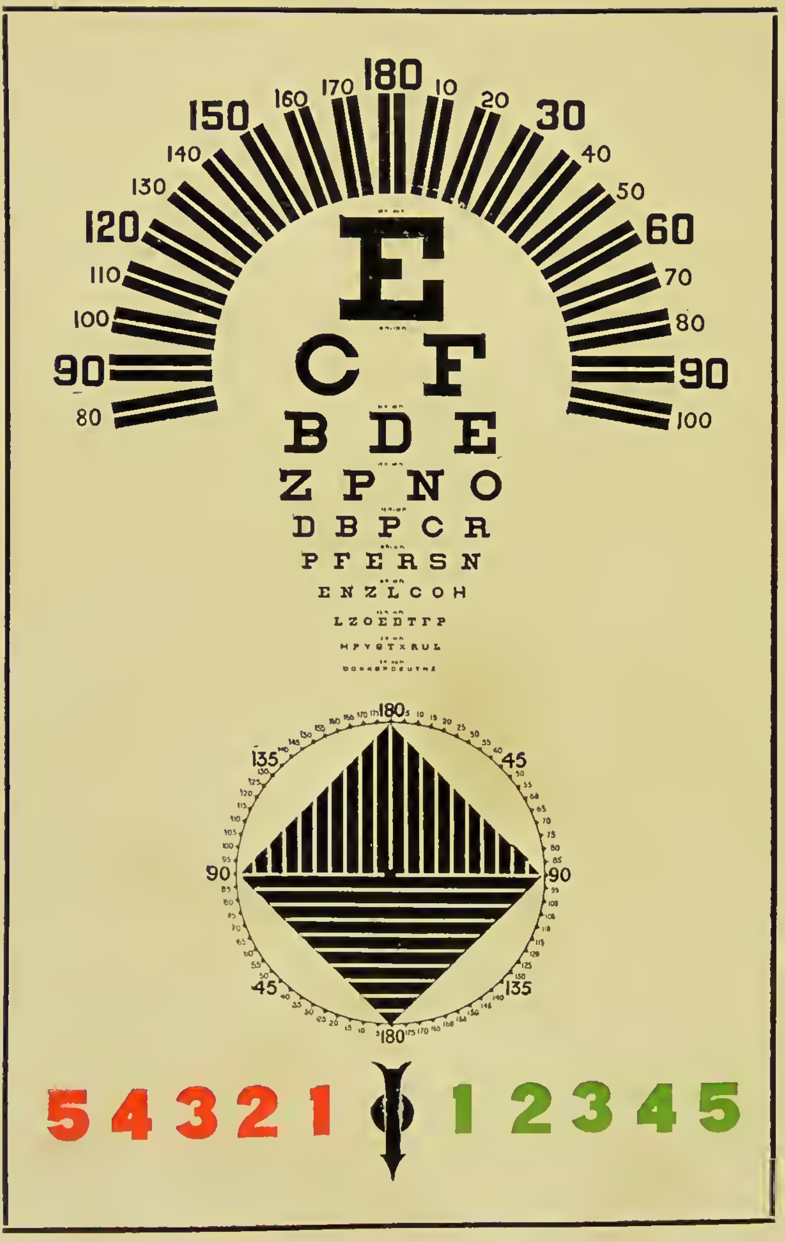
Subjective sight testing consists of selecting, by a process of exclusion, that sph. and cyl. lens needed to neutralize the optical error of an eye. A judgment as to the right correction is made solely by the visual effects obtained from certain lenses, combined with a knowledge of what they should give in certain circumstances. Thus, an over-correcting Cx. sph. makes V. worse, while an over-correcting Cc. sph. *does not further improve it* and, practically, the same applies to cylindricals.

In subjective testing a great deal indeed depends upon the nature of the question and the manner in which it is put to elicit the desired information. The optician, for instance, wants to know whether a certain Cx. sph. is not strong enough or a Cc. is too strong; he therefore has to find out whether *V. does not become worse* when an addition of + power is made to a lens that is in the frame. If he wants to know whether a Cx. is too strong or a Cc. not strong enough, he must ask whether the addition of Cc. power *causes improved V.* Unnecessary and vague questions must be avoided, and they must be of a nature that *forces a reply* that will give the *desired knowledge* of what the next step is to be—whether the change shall be in the direction of increasing, or of decreasing, the power of the lens which is in front of the eye at the moment.

It is advisable to increase or decrease + or − power by holding another weak lens in front of the one in the frame, as then a comparison can be made far better than if the one lens be removed and another inserted.

Thus suppose a subject has a +2·0 S. before the eye and V. = 6/4·5; if it is still the same with +·25 S. added, the +2·0 S. is to be exchanged for +2·25 and the process repeated; on the other hand if No. 4·5 is blurred with the added +·25 S., no further + power will be accepted. But if with −·25 S., V. is improved so that perhaps the next line is read, the +2·0 S. is exchanged for +1·75 D. and so on. Similarly with a case of myopia the optician needs to find out whether an added − power enables the subject to read *a line of smaller types*, or whether an added + enables him to *still read the same line*, or in As. whether a certain cyl., either + or −, leaves the blacker bars still black, equalizes them with those at right angles, or renders the latter the clearer.

THE "ORTHOPS" CHART.



Size 40″ × 25″.

he *radial* lines ot the dial (shown vertical above) are directed outwards from the re ; the *tangential* lines are at right angles to these. The revolving dial is so used , in all cases of astigmatism, the radial lines are those which are most clearly seen.

he numeration of the meridians on the fan and dial is so arranged that, when in ion, the apex of the radial group on the dial indicates the meridian of the axis of the ired cylindrical in a trial frame having standard notation.

very detail of the "Orthops" Chart has been determined or calculated with a definite t, and on scientific principles.

To face page 71

As stated previously, the optician can only—in the absence of cycloplegia—deal with the manifest optical condition so that in general it may be said that the theoretical correction of H. and M. is, respectively, the strongest + or weakest − lens with which the highest possible visual acuity is obtained *without excessive Ac. being used.* The latter is a variable quantity governed by the amplitude possessed and by the muscular balance; in H. it is an amount equal to the latent; in M. it varies between 0 in the higher, to an amount not usually exceeding 1 D. in the lower degrees. Since Ac. varies with and without binocular fixation, the measure, and even apparent nature, of a defect may differ when both eyes are engaged. The measure of a defect or its theoretical correction is not necessarily what is actually required.

Throughout this chapter it is, of course, presumed that the eyes are healthy and that normal vision, as defined in Chapter IV., is reached in all cases. The precautions as to disease, and cases unsuitable for correction by the non-medical refractionist, are dealt with in a separate chapter.

Summarized Visual Indications.—In H. and H. As. the vision may be either *normal or subnormal.* In M., M. As. and Mixed As. the vision *must be subnormal.* Thus if V. is normal the condition *must be* either Em., H. or low H. As. and *cannot be* M., M. As., or Mixed As.; while if V. is subnormal the condition may be that of any single error or any possible combination of errors.

Routine of Subjective Sight Testing.—It is presumed that the "Orthops" chart is employed but the descriptive matter applies equally well to any other types and charts. The Orthops chart, however, renders subjective sight testing, especially for As., particularly definite and easy; it is illustrated opposite this page. Although the following routine may sometimes need to be broken, or altered, it is that which should be followed in ordinary cases.

1. Take the binocular V. by causing the types to be read as low as possible.
2. Occlude O. S., take and *record* V. of O. D.
3. Occlude O. D., take and *record* V. of O. S.
4. Put on and adjust trial frame. Occlude O. S.
5. Determine the presence or absence of manifest H. in O. D. or the presence or absence of M. and—

    (*a*) Fog the sight by over-correcting H. or under-correcting M.

    (*b*) Determine As. if present and roughly the principal meridians with the fan.

    (*c*) Determine exactly the principal meridians with the diamond.

    (*d*) Correct the As.

    (*e*) Complete the correction of the H. or M. according to rules given.

    If there is no As. but simply manifest H. or M., (*b*), (*c*) and (*d*), of course, do not apply.

6. Occlude O. D. and test O. S. in a similar manner.

7. Compare V. A. of each eye.

8. Take P. P. of each eye separately with correcting lenses. If in 7 or 8 there is inequality, revise 5 and 6.

9. *Record d*, *e*, 6, 7 and 8.

10. Take the Hor. and Ver. muscular balance. *Record.*

11. Test binocularly if necessary.

12. Change the spherical correction if necessary. *Record.*

13. Test ability to read hand types. *Record.* If subnormal also the distance.

14. Determine Pres. if necessary.

15. Correct Pres. if present. *Record.*

16. Test field of vision. *Record.*

17. Ascertain general effect of the proposed lenses for distance and reading, also the binocular V.

18. Fit, or measure for, the frame. *Record.*

The Practical Testing of the Various Conditions.

The Spherical Test.—We endeavour to find the highest possible + and the lowest possible − spherical power with which the best V. A. is obtained. Now to select the cylindrical *it is absolutely essential that the eye be fogged* by an over-correcting + or under-correcting − spherical; hence the power of the spherical is determined after that of the cylindrical. When the astigmatism has been corrected, + sph. power is added so long as it improves or *does not make vision worse* or − sph. power is added so long as it *improves vision.* This addition is made whether there is, or is not, an original spherical and to avoid repetition in the following notes we will term this the *spherical test.*

Low to Medium Hypermetropic Errors.—If V. is normal or nearly so, say 6/9 or better, a weak + sph. is employed and whether it does or does not blur, its strength is increased until, or so long as, V = 6/9. Then As. is sought and if none is determined the fogging lens is reduced by adding − power until vision is normal. There is H. of low degree if best V. is obtained by the addition of a Cc. which is weaker than the Cx., and there may be Em. if the two are numerically equal.

If As. is determined, it is corrected with a − cyl. and the ultimate result of the *spherical test* may determine the manifest condition to be a low degree of compound H. As., Simple H. As., mixed As., or even M. As. Suppose a case where, without lenses, V = 6/6 and that it is fogged to 6/9 by + 1 D. Then if − ·5 D. cyl. corrects the As. there is a manifest condition of :—

(*a*) Compound H. As. if best V. A. results from adding − ·25 sph., since then the final combination is + ·75 S. ⊂⊃ − ·5 C.

(*b*) Simple H. As. if best V. A. results from adding − ·5 sph., since then the final combination is equivalent to + ·5 C.

(*c*) Mixed As. if best V. A. results from adding − ·75 sph., since then the final combination is + ·25 S. ⊂⊃ − ·5 C.

(*d*) Simple M. As. if best V. A. results from adding − 1 sph., since then the final combination is equivalent to − ·5 C.

(*e*) Compound M. As. if best V. A. results from adding − 1·25 sph., since then the final combination is − ·25 S. ⊂⊃ − ·5 C.

Of the above (*d*) would be exceptional and (*e*) impossible if + 1·0 S., fogged the V. to 6/9. These two (*d*) and (*e*) have been added rather as illustrations of the changes in the nomenclature of the class of As. which results from the addition of sph.'s to a given sph. and cyl. already in the frame. If, in cases like these, the − cyl. is fairly strong compared with the + sph., say, − ·75 D. or − 1 D., not only is it possible that no reducing − sph. is needed to improve the sight but, on the contrary, more + sph. power may be accepted without blurring.

Medium to High Hypermetropic Errors.—If V. is subnormal, a + sph. of, say, 1 D. is employed and if this does not impair, or if it improves V., the case is obviously one of H. and the strength of the lens is increased until, and so long as, the highest V. A. is obtained. If V. is made normal the power of the + sph. should be still further increased by about ·75 D., so as to fog to 6/9 and the test is completed, as described in the previous article, by (*a*) determining the As. if any, (*b*) correcting the As. with a − cyl., (*c*) applying the *spherical test.*

If V. cannot be made normal with any + sph. it is because there is, probably a considerable degree of As. When the best possible sight is obtained, As. and the principal meridians should be determined. The strongest + sph., with which the originally clearest bars are still clearly seen, is selected and the test continued by finding the strongest + cyl. which equalizes the bars of the astigmatic dial. Or alternatively, the strongest + sph. is found with which the originally blurred bars are clearly seen, and the test continued by finding the weakest − cyl. with which the other bars are made equally clear. The latter method is to be preferred but in either the routine is completed, after the cyl. is selected, by the *spherical test.*

With the + sph. first tried the effect may be indefinite, because (apart from the possibility of M.) there may be H. of so high a degree that a + 1 D. causes no improvement in sight. In these cases, by increasing the power of the + sph. some definite deduction can be drawn.

If notwithstanding increased + power the improvement or blurring of V. is still vague, the case is probably one of (*a*) simple H. As. (*b*) low H. with high H. As. (*c*) mixed As. with the H. predominating. In these cases the As. is determined and corrected by finding the strongest + sph. with which either set of bars of the chart is clear, and equalizing the two sets by the weakest – cyl.; the *spherical test* then follows. If the ultimate – cyl. is numerically higher than the + sph., the case is mixed As.; if it is of the same power, there is simple H. As., and if of lower power there is compound H. As. In some of these last described, there being little or no H., the case may be better and more easily tested by employing a + cyl., instead of the + sph. and – cyl., followed by the *spherical test.* If from the latter a + sph. is accepted, the case is compound H. As.; if no + sph. is accepted, it is simple H As., and if a – sph. improves the sight it is mixed As.

Low Myopic Errors.—If V. is subnormal and a + sph. blurs, the case is probably M. If V. is better than 6/60, the error cannot be of so high a degree as 3 D. An attempt should at once be made to determine As. if V. = 6/36 or better, or after improving it to 6/36 when, unaided, it is less than 6/36. Should As. not be then determined, V. should be improved from 6/36 to 6/18 by a Cc. sph. and a similar attempt made; if again unsuccessful the V. should be further improved to 6/9 and again As. is to be determined if possible. To improve V. from 6/60 to 6/36, from 6/36 to 6/18 and from 6/18 to 6/9 requires in each case about – ·75 S. and the weakest possible – lens must always be employed. If the As. is high it will be determined when V. = 6/36, if low, but over say 1 D., it will be determined at 6/18; if less than 1 D. it will be determined at 6/9. If then no As. is apparent, the case is one of simple M. and is completed by the *spherical test.*

If As. is determined at any of the three stages mentioned, it must be corrected with the weakest – cyl. with which the two divisions of the As. diamond become equally clear. After the cyl. is selected the *spherical test* is applied but this will never result in a reduced Cc. power if due precaution has been taken to keep the M. so far under-corrected.

Medium and High Myopic Errors.—If a + sph. blurs, when V. is less than 6/60, and is improved by a – sph., the latter is increased in power until V. = 6/60, further improved to 6/36 and the test then continued as in low degrees of M. errors. This is the usual procedure in compound M. As.

When the improvement in V. is vague and indefinite with a – sph. or if no improvement results, a determination of As. should be at once made if possible. This may occur in simple M. As. of high degree, or in compound M. As. with the As. high and the M. low, or in mixed As with the M. predominating. The correction of the As. being made, if from the *spherical test* there results a – sph. there is compound M. As., and if a + sph. there is mixed As.; if no sph. is needed, there is simple M. As.

Mixed As.—The correction of cases of mixed As., where the one error is low compared with the other, has already been mentioned. Where the H. strongly predominates over the M., or the M. over the H., the case resembles respectively simple H. As. and simple M. As. Where V. is subnormal and a + sph. blurs, or vaguely improves V., or a – sph. has a similar effect, it is probably because the lens improves vision for the one principal meridian and impairs it for the other. Generally in such a case, without lenses, the perception of all the As. bars is equally bad. Putting up a + sph. lens of, say, 2 D. the As. may at once be determined. If this occurs there is selected the strongest + sph. with which the one set of bars on the As. diamond is clearly defined. When this + sph. has been selected, the correction of the As. is made with the weakest – cyl. that equalizes the two halves of the diamond and gives the most acute V. The Cc. cyl. must, if the case be one of mixed As., of necessity be numerically higher than the + sph. Or the test can be made with a – sph. and a + cyl., the sph. being the weakest and the cyl. the strongest that gives best possible vision.

When mixed As. is suspected the stenopæic slit can be employed with a, say, + 2 D. sph. The hypermetropic principal meridian is located by rotating the slit until best V. is obtained, and the correction for that meridian is found by selecting the strongest + sph. that gives the most acute V. The lens is withdrawn, the slit turned to the meridian at right angles to the first, and the weakest – sph. that gives best V. is selected for that meridian. Having found the two principal powers approximately, the slit is then removed, and the equivalent – sph. ⊂⊃ + cyl. put up. A final adjustment of the sph. and cyl. must be made, increasing the + and reducing the – power to obtain best equality of the two parts of the As. diamond and the greatest acuteness of V. As a rule, a change of the sph. element of the combination renders necessary a change in the cyl. element and *vice versa*.

The Binocular Spherical Test.—In all cases the binocular test would, most likely, cause a change in the measure of the sph. correction and even alter the apparent nature of the defect. The change is nearly always in the direction of higher + and weaker – sphericals. Thus an apparent Em. monocularly, may manifest H. in the binocular test by accepting a pair of weak + sphericals.

The acceptance of a pair of weak + sphs. when the monocular measure of the defect was a – cyl. converts apparent simple M. As. into mixed As. Even low apparently compound M. As. may, by the acceptance of + sphericals binocularly, become manifestly compound H. As. The essential point is that the true measure of the manifest error is not obtained until after the binocular test has been made.

Notes on Practical Testing.—With Cx. sphericals it is not necessary to try the effect of everyone between the determining and the correcting lens; several in the series can be skipped and then, if one tried proves too strong, its strength can be reduced, either by adding a Cc. or by changing for a weaker one. With Cc. sphericals the power of the lens should be very slowly increased by half, or even quarter, diopters when V. is 6/60 or better. If V. is less than 6/60 the power of the lens may be increased rapidly until

6/60 is reached. Results not obtained within a reasonable time will most likely prove unsatisfactory, as the eyes get tired and fail to respond to slight differences of optical effect. It is better to make another test on another occasion, giving, if thought advisable, a pair of sph. lenses for temporary use. The general effect of the selected lenses should be tried as to their being comfortable when looking about, and especially for reading. If the lenses are required for special distances in Pres., as for pulpit reading, music, reading, clerking, carpentering, etc., the glasses needed for such distance should be selected and their suitability tested.

Correction or no Correction.—Low errors of refraction, especially in young and robust individuals, frequently do not need correction, although later in life they may. At the same time, as previously stated, it is the low errors rather than the high ones that give rise to asthenopia; the person who is most proud of the keenness of his sight is the one who is most likely to suffer from the effects of eye strain, although of course he does not think so. Low errors of refraction are more likely to need correction when—

(*a*) The disposition of the individual is of the nervous type.
(*b*) The health is bad or delicate.
(*c*) After an illness.
(*d*) There is constant application of the eyes to close work.
(*e*) The occupation is followed largely in bad or artificial light.
(*f*) The pupils are large.

Whether a correction is needed or not must be a matter for consideration in each individual case, and no definite rules can be laid down.

It must be remembered that a person seeks advice about his eyes either because he has painful sight constantly or in near vision only, or because he has defective distant or near vision, or both. The question is, of course, whether lenses will certainly, or probably, rectify the conditions for which the optician is consulted.

CHAPTER XIII

SUPPLEMENTARY TO SIGHT TESTING

Outward or Objective Signs of Ametropia.—Frequently the general contour of the head and face and appearance of the eyes themselves are characteristic of certain errors of refraction. Thus H. is often associated with small sunken globes in which the pupil may be small, the anterior chamber shallow and the sclerotic takes a strong curve backwards near the equator. In addition the hypermetropic eye, being more nearly spherical in shape, moves rapidly and over a large field while both eyes frequently have an appearance of divergence owing to the comparatively large angle α. Since the foregoing are characteristic of a short axial length, the external appearances of a myopic eye are naturally the reverse; thus the globe is prominent, the pupil is large, the aqueous is deep, and the movements sluggish, the myope rather turning the head than the eyes in oblique vision; the binocular appearance is that of convergence owing to the relative smallness of angle α. Astigmatism is sometimes indicated by a slightly elliptical cornea and pupil and anisometropia by general asymmetry of the head and features. Astigmats particularly indulge in the habit of holding the head sideways when looking at an object, and especially during a test, or if they are wearing sphericals only or incorrect cylindricals.

Of course, there may be many exceptions to these indications, especially those for H. and M.; thus myopia is often found in apparently small sunken globes and hypermetropia in bold prominent eyes so that the above must by no means be taken as applicable in every case, the apparent size depending on the palpebral opening. Muscular troubles may sometimes be accompanied by inclination of the head or glasses, and slow response of the iris, to altered illumination, indicates sluggish Ac. whether in H., M., or Pres.

The Pinhole Disc.—In general subnormal vision must be due to either absence of a sharp retinal focus, to amblyopia, to opacity or disease and the pinhole is employed to distinguish, as far as possible, between these conditions. If the defective sight be due to ametropia the disc will improve V. by confining the light entering the eye to very narrow pencils so that the discs of confusion on the retina, no matter where the latter may be with respect to the principal plane, are correspondingly small. At the same time the intensity of illumination is so much reduced that the sight is rarely so good as with the correcting lenses, provided it be a regular error of refraction.

If, however, the defective sight be due to amblyopia, to disease or to opacity of the media no improvement, or even a reduction of V. will result, thus indicating that the case is not solely optical.

The disc may improve the sight and yet there may be disease, part of the reduction of vision being due to the latter and part to Am., but in such cases no lenses would make vision normal.

The disc may also improve the sight, yet it does not follow that lenses will subsequently improve it as in cases like irregular As. and conical cornea

The disc may fail to improve the sight, or even reduce it, and yet there may be an optical defect and it does not follow that medical or surgical treatment would be of any use, as for instance where there is a nebula of the cornea which is incurable, or in cases of partial amblyopia due to other than an optical defect.

Again when V. is fairly good, say, 6/9 or 6/12, it is almost useless to employ the pinhole as no improvement with it is to be expected, even although the deficiency in sight is caused by an error of refraction; this results because the reduction of light admitted to the eye counteracts the sharpening of the image. Nevertheless some people with V. = 6/4·5 obtain a sharper degree of vision with the disc but, in such cases, its use would not be called for. When lenses fail to give the same improvement as the disc an irregular error may be suspected.

Used with a knowledge of its limitations the disc is a valuable little instrument. It does not definitely determine or exclude disease nor does it distinguish between disease, opacity and amblyopia; the tale it tells is that if it improves vision the eye is in all reasonable probability perfectly healthy, while if it fails to improve the sight the eye is very probably not healthy, and anyhow has something more than a purely optical defect.

When using the disc the one eye is occluded and the pinhole placed in the trial frame in front of the other, care being taken that the aperture is directly in the line of vision. Some people find it difficult to see through the pinhole when in the trial frame so that it is sometimes better, the one eye being occluded, to allow the subject himself to put the disc in front of the other eye, using the right hand for the right eye and the left hand for the left eye. If V. is much reduced, say, below 6/60 the large pinhole should be used, while the small one is preferable if V. is 6/60 or better.

Focal Illumination is used for examining the lids, conjunctiva, cornea, aqueous, iris, pupil and crystalline lens. An artificial luminant is placed conveniently in front and rather to the side of the eye and the light, concentrated by a convex lens of about 13 D., is cast obliquely on to the part of the eye to be examined; the lens is moved slightly backwards and forwards in order to get the best possible illumination. A magnifying lens of about 10 D. used in conjunction with the condenser renders the examination easier. Opacities (nebulæ) of the cornea or crystalline and imperfections of the iris can be seen by this method. For the crystalline the light should be projected rather more perpendicularly. The cornea can be also examined with the ophthalmoscope having a 16 or 20 D. Cx. lens behind the sight-hole, and the iris and crystalline with a somewhat weaker one, the part of the eye under examination being at the focal distance of the lens used.

Cycloplegics and Mydriatics.—As a rule a cycloplegic is also a mydriatic. Cycloplegics paralyze the sphincter of the ciliary muscle and therefore cause the true static refraction of the eye to be disclosed. Mydriatics paralyze the sphincter of the iris and therefore enlarge the pupil, thus facilitating ophthalmoscopic examination of the fundus and retinoscopy, for which purposes they are chiefly employed.

The necessity of cycloplegia in some cases of Am., especially in children, is unquestioned, but the use of drugs for the purpose of sight testing is rapidly becoming less as knowledge of the work increases. Also the advantages of not correcting Am., as found in the artificially passive eye, are becoming more recognized although, of course, it does not follow that for instance, a full correction of H. is given because the error has been measured under cycloplegia. Cycloplegics are now rarely used with adults, and practically never with people over 40, since they are liable to cause an attack of glaucoma when there is a tendency thereto. The advantages and disadvantages of their use depend on each individual case but drugs should never, of course, be employed by a non-medical man.

With the Ac. paralyzed all eyes, as a rule, disclose less refraction which averages ·5 D. to 1 D., so that a person H. 1 D. under atropine is approximately Em. in ordinary vision; one who is Em. under atropine is M. about 1 D. when the drug wears off. It must not, however, be forgotten that the accompanying mydriasis discloses a larger area of cornea and crystalline, and this peripheral area, not effective in ordinary vision, may entirely change the mean refractive power. We know that the periphery of the cornea has less power than the centre, and although this is more or less counteracted by the crystalline, the total enlarged area may be of less power than the central portion. On the other hand the peripheral refraction may mask the changes caused by the relaxed accommodative action. Anyhow it is pretty well certain that the mean refractive condition of a dilated eye at rest may be quite different from the mean refractive condition of that same eye at rest but not dilated. But these points, however interesting, do not diminish the value of the knowledge to be obtained from cycloplegia when it is necessary, but the measure of the Am. thus obtained cannot be regarded as representing that of the eye when the pupil is active, and still less of the eye when the Ac. is normally in action.

Atropine causes strong cycloplegia and mydriasis. Its effect does not completely pass away for 7 or 10 days. Homatropine causes partial cycloplegia and mydriasis, and its effect lasts about 24 hours. Cocaine and some other drugs are mydriatics, but cycloplegics only to a slight degree. The effect of an instillation of cocaine lasts from 30 minutes to 2 hours according to the strength used. Eserine causes strong spasm of accommodation and myosis, and pilocarpine, which contains the principle or alkaloid of eserine, does the same to a lesser extent. Cocaine and other drugs, such as eucaine and holocaine, are local anæsthetics. The time taken for the effects of atropine to pass away is shortened by the use of a weak solution of eserine; this also greatly lessens the dangers of setting up glaucoma in an adult.

Notes on the Eyes in General.—Fatigue and eye-strain, quite apart from any abnormality in the way of ametropia, muscular insufficiency, etc., may be experienced in many ways and from many causes. Thus muscular fatigue may result from work done with the eyes excessively elevated or depressed or when lying down. Similarly strain is thrown on the eye generally when reading is done in a jolting railway carriage or bus where the lighting also is not generally too good; prolonged use of the eyes in such circumstances as these may give rise to the habit of holding the work very close even when there is no necessity for it. Work of any kind under conditions detailed above should be avoided, and especially should the eyes be rested or little used during illness or convalescence.

Notes on Children's Eyes.—Seeing the great influence that the sight of early childhood has upon subsequent life, it is highly important that eyes should be given the best possible chance of healthy development. We have seen that myopia, squint, etc., and their attendant troubles can only be arrested if taken in time and at a sufficiently early age. It is very essential, therefore, that children should be periodically tested and corrected, if necessary, before the serious study and application of the eyes to near work in school commences. The actual adaptation of lenses in most cases calls for the employment of a cycloplegic, and therefore the tests should be made by a medical man or by an optician working in conjunction with him. However cursory the examination of a whole school may be, yet it is better than nothing since vision can be noted, and those cases obviously needing further and more detailed examination, quickly sorted out.

Toys and playthings should not be small or of such nature as to call for close vision, and the contemplation of distant objects should be encouraged; further, the hours of close work, especially home work, should be the minimum possible. It is very often the case that the backwardness of a particular child is ascribed to stupidity when in reality he is handicapped by some ametropic condition giving rise to defective or painful sight. Children should not be allowed to stoop when reading, nor should they hold the work very near to the eyes; books should be printed in bold clear type and on good white opaque paper. Bending over the fire to read by its light is a favourite habit, and one calculated to bring on myopia and eye-strain generally perhaps more than anything else. For the same reason desks and chairs should be designed on common-sense principles, and some allowance made for the different sizes of children to obviate the necessity for stooping among the taller ones; apparently some people seem to think that all children are the same size. Finally, teachers should be taught or allowed to arrange classes so that close work is done at hours when the light is sufficiently good. Daylight, of course, is best but if artificial illumination must be employed it should be evenly distributed, perfectly steady and ample in quantity—too much rather than too little.

Points on Luminants, etc.—Good illumination is that which is steady, evenly distributed and sufficiently bright; direct light from the source should not be allowed to enter, or in any way to shine directly on to the eyes. In the latter case vision is obscured or clouded by the diffuse light inside the globe itself which interferes with the view of the object or work in hand. Especially in prolonged close work, such as reading or writing, there should be absence of all flicker, and highly coloured sources should be avoided. The most perfect illuminant is a bright white light thoroughly scattered by passage through ground glass or reflected from a matt surface so placed that no shadows are cast as, for instance, that of the hand in writing.

It is, of course, well known that certain sources, like the electric incandescent or arc lamps, are very rich in actinic or ultra violet light, prolonged exposure to which is highly injurious to the retinal elements, and it is a well-known fact that workers in electric power stations, etc., are very liable to suffer from retinal asthenopia and general irritation. When such luminants are unavoidable the use of medium amber, yellow, or spectrum blue glass, which are impervious to ultra violet, is advisable as a protection. Monochromatic light should be avoided, but any colour which is soft and largely diluted with white is not objectionable. To obtain sufficient natural illumination in a room the window area should be about one-fifth of the floor.

In the decoration of rooms and living apartments, very dark colours are depressing while, on the other hand, very light tints are fatiguing to the eyes; pale green or blue, gold, grey and art toned papers are good. Red and old gold stimulate, but purple and dark blue depress; for this reason the former colours are generally used in dining rooms and places of amusement, and they also give the effect of spaciousness.

Print Types.—The legibility of print depends on the contrast between the type and the background; the blacker the former and the whiter the latter the better the print stands out. An extremely white ground is, however, fatiguing to the eyes; cream-coloured paper, although less perfect than pure white as regards contrast, is more agreeable and to be preferred for general use. Coloured paper and glazed paper which reflect light regularly are objectionable; indeed, at certain angles of incidence of the light, reading or writing sometimes becomes impossible. Thin paper, which shows the type from the reverse side, is apt to be irritating and should therefore be avoided.

Thin, worn and *solid* type are bad; broad and *leaded* type are good. The greater the space—within reason—between the various letters and words, the more easily is reading achieved. If the type is small the length of lines should not exceed say 6 cm. and for large type 10 or 12 cm.; the latter is just taken in comfortably by the eyes without turning the head or over-exerting the lateral muscles. If avoidable, type should not be smaller than 1·5 mm. in length, and 2 mm. should be the smallest in school books; the thickness of the thin lines of each letter should not be less than ·25 mm. The intervals between letters, words and lines, respectively, should not be less than 1, 2 and 3 mm. approximately. The following are the approximate lengths of some of the best-known styles of type:—

Double Pica	3·00 mm.
Great Primer	2·50 ,,
English	2·00 ,,
Pica	1·75 ,,
Long Primer	1·50 ,,
Brevier	1·25 ,,
Nonpariel	1·00 ,,
Pearl	·75 ,,
Brilliant	·5 ,,

Snellen's types have the following dimensions:—

No. of type = distance in M.	60	48	36	24	18	12	9	6	4·5	3	2
Size in mm.	87	70	52	35	26	17·5	13	8·75	6·50	4·37	2·9

The corresponding series in English measure is:—

No. of type = distance in feet	200	160	120	80	60	40	30	20	15	10	6·6
Size in inches	3·5	2·8	2·1	1·4	1	·7	·5	·35	·25	·18	·12
Equivalent metric No.	60	48	36	24	18	12	9	6	4·5	3	2

Tests for Malingering.—The tests for determining the presence or absence of simultaneous binocular vision, and for malingering, are similar, except that in malingering one obviously cannot rely on the subject's answers. It must be remembered that a maligerer is not easily trapped into making errors and that he can only be unmasked by confusing him; this may be done effectually by simple tests. The term *bad*, or *blind*, in this article is applied to the eye which is *claimed* to be defective.

The *bar*, *friend* and *prism* tests described for testing binocular vision (*q.v.*) need not be here repeated.

The Bar Test as a malingering test, is of little value as the malingerer would quickly learn how to deceive the examiner.

The Prism Test is very effective and, in addition to the procedure mentioned for testing binocular vision, the prism may be placed before the presumably blind eye; if the good one makes an associated movement, the former has vision. If, when the prism is before the good eye, the supposed blind one moves, or if when it is before the blind eye the good one does not move, nothing is proved.

The Friend Test, if the glasses are put up without their colour or the object being seen, forms a most excellent malingering test and especially so if the glasses be changed about.

Type Test.—On a piece of white paper alternate words are written or printed in red and black. If when red glass is placed in front of the good eye, the subject can read the print without hesitation, he is undoubtedly a malingerer, since the red letters are invisible through the red glass. The glass and letters must of course be selected as to tint so that the red letters are indistinguishable from the apparently red ground.

Light Test.—The sound eye being completely covered, note whether the blind eye responds to the influence of light by contraction of the pupil. Although there is said to be one form of blindness in which the pupil does react to light, it is very rare and such reaction strongly points to malingering. This test is not, however, a proof that an eye is not highly myopic since, in such a case, the pupil does respond to a very bright light. Further, immobility of the iris might be obtained by the employment of a drug. The sympathetic pupillary action of the good eye, screened from the light, may also be watched as the bad eye is alternately exposed and occluded.

Lens Test.—Various tests for malingering can be made with sph. and cyl. lenses and noting the replies made to questions. For instance a very strong Cx. or Cc. might be put over the good eye and a plano over the supposed defective one; if the subject can still see distant or near type, it must be with the eye before which the plano glass is placed.

Confusion Test.—The subject is made to read some print and a prism base down of about 8° is suddenly placed before the bad eye. This being too strong to be overcome, vertical diplopia results, and the resulting confusion caused by the doubled and overlapping images renders reading almost impossible. Unless the subject closes one eye this is an excellent malingering test, since the slightest hesitation when the prism is put up is easily apparent.

Diplopia Test.—Occlude the bad eye and cause diplopia in the good one by a prism of 6° placed base down in a such a way that the edge just bisects the pupil. Then uncover the bad eye, at the same time moving the prism upwards, and ask whether the object appears double. If it is, one image must be seen by the pretended blind eye.

Place a 6^{Δ} prism base down in front of the bad eye and inquire whether the object looked at is seen double; the answer will, of course, be in the negative. If the prism be now placed in front of the good eye and the object is said to be seen double, binocular vision is proved to exist.

Catch Tests for malingering are numerous of which the following are examples: On being asked to look at his hand, when the good eye is occluded the malingerer will do so readily if really blind; if not he will probably look somewhere else. The good eye being occluded, the subject is directed to cross a room, an obstacle being placed in his path; his attitude on approaching it will show whether it is seen or not.

Points on Other than Purely Optical Cases.

While it is no part of the optician's work to diagnose specific pathological conditions of an eye, he needs to recognize a healthy condition, or to appreciate a *non-optical condition.*

The eyes may be regarded as free from active disease if (*a*) the visual acuity (corrected V.) of each eye is normal and that of the two equal. (*b*) No. 1 type can be read at the natural distance, if necessary, of course, with corrective lenses. (*c*) The field of vision of each eye is normal. For the latter purpose the field need only be tested in the horizontal and vertical planes. As discussed at the beginning of this chapter, improvement of V. with the pinhole determines subnormality of vision due to refractive error, but does not prove (*a*) absence of disease, (*b*) absence of abnormal curvature which lenses will not properly correct, *i.e.* conical cornea or irregular As. Focal illumination (*q.v.*) will disclose defects of the cornea, iris and crystalline lens; ophthalmoscopic indications of diseases of the fundus are to be found in Johnson's "Pocket Atlas of the Fundus Oculi," published by Adlard and Son. Most diseased conditions are accompanied by reduced visual acuity after the optical correction has been arrived at; subnormal V. A. must indicate: (*a*) Disease which requires treatment. (*b*) Amblyopia, abnormalities or lesions left by disease which may, or may not, require medical or surgical attention. (*c*) An incorrect refractive measurement.

Conditions Demanding Medical Examination.—(*a*) Where the pinhole, properly applied, does not improve V.

(*b*) Where corrected V. is subnormal (as already defined).

(*c*) Which present symptoms of disease, injury, or structural abnormalities, other than ordinary errors of refraction.

(*d*) Which present symptoms of pain disproportional to any refractive error discovered.

(*e*) Where, in children, there is M., high As., spasmodic Ac., or H. of which a considerable part appears to be latent.

(*f*) Of high or progressive M. in adults.

(*g*) Of apparently rapidly increasing Pr. or of myopia coming on in adult life.

(*h*) Of squint, double vision or high muscular insufficiency.

(*j*) Where the field of vision is contracted, or

(*k*) Those which are *not fully understood* by the optician.

The competent optician appreciates that there are many cases of refraction where, not only has the action of the light to be modified, but treatment—local or general—may be required. Further, he knows that some cases are better measured or corrected with the aid of cycloplegics. The greater his skill the smaller is the number of cases in which normal vision is not obtained by correction, while on the other hand the greater is the number which he considers would be better examined and pronounced upon by the oculist. If a case is referred to a medical man and no medical or surgical treatment is needed, at least no harm results. If a case requiring medical or surgical treatment is not so referred, there is danger to the client. Everyone is liable to mistakes and errors of judgment, but no conscientious optician will knowingly take on himself the responsibility of deciding in doubtful cases because the first symptoms of many general diseases may be manifested in the eyes.

In the following a few abnormal conditions are briefly described but no serious attempt is made to indicate the disease to which a symptom points, this being of little importance to the optician. Some symptoms are common to widely different troubles.

The Eye.—*Protrusion* or *lateral displacement* is a serious symptom pointing to tumour, exophthalmic goitre, etc. An early symptom of goitre is that the upper lid does not descend equally with the eye when the latter is lowered.

The Lids.—*Ptosis* (drooping of the lids); inability to open or close the eyes, indicating paralysis, general exhaustion, hysteria, inflammation of the lachrymal gland, trachoma, etc. (Many people, however, normally cannot close one eye without also closing the other.) Displacement of the lids or lashes.

Nictitation (constant winking or blinking and twitching of the lids) indicates nervous conditions which may, or may not, be due to eye-strain.

The Cornea.—Bloodvessels visible on the cornea show a pathological condition. If specially on the upper part, they may indicate trachoma (granular lids) which is of a very infectious nature; if they diverge from a common point there may be an ulcer or a foreign body. Haziness of the cornea or a pink or red zone surrounding or adjoining it.

Nebula (opacity of the cornea) is usually the result of an ulcer, wound, granulated lids, or general inflammation of the cornea. Even if very faint and diffuse, it causes great loss of acuity especially if on the visual axis. It is disclosed by oblique focal illumination, employed in conjunction with a magnifier, and should be looked for when vision is impaired. It is for the medical man to decide whether treatment is of use or not.

A very minute corneal opacity is termed a *macula;* a large one a *nebula;* a very dense white opacity a *leucoma.* The last is due to deep destruction of the cornea and replacement by scar tissue. It is a curious fact that a very obvious nebula may, if not extensive, cause less reduction in acuity than an almost invisible one. The reason is that the former acts more or less as a definite stop, leaving effective areas of clear tissue while the latter although faint, may obstruct the whole of the pupil.

The Arcus Senilis is a whitish ring around the periphery of the corneæ of old eyes and has no pathological significance; it appears as if located in the periphery of the irides, but is not so actually.

Conjunctival symptoms are mainly those of lachrymation, pain, redness, discharge, thickening or discoloration.

Irides indistinct or of dull, discoloured or thickened appearance; the iris of one eye differing from the other.

Pupils widely dilated (mydriasis), small and inactive (myosis); inequality in size, irregularity of shape, inability to contract with Ac. and Con. or to react to light and darkness, or sluggish response (except in old people).

Abnormal Vision such as smoky, hazy, quivering, flickering or occasional loss of sight. Spots or clouds before the eyes. Coloured vision. Abnormal vision as *micropsia* (objects look small), *megalopsia* (objects look large) or *metamorphopsia* (objects look distorted) are serious symptoms. The alteration in the size and form of objects points to destructive changes in the rods and cones of the retina. Abnormal visual sensations like flashes of light, scintillation, jets or balls of fire, or persistent after-images.

Muscæ—the seeing of specks, webs, or strings of pearls—if abundant may be serious and should cause the case to be sent to the oculist; they generally indicate vitreous trouble. If only seen occasionally and when looking at a bright field they may be ignored as harmless.

Hemeralopia and Nyctalopia.—In the former case the subject sees comparatively better in the day, in the latter towards evening, but the two terms are frequently confused. The causes are various, *e.g.* cataract, tobacco amblyopia, exposure to excessive sunlight in the tropics, nervous and constitutional disorders; they are essentially cases for medical investigation. Uncorrected M., however, also causes worse vision in the dusk owing to increased diffusion circles brought about by the dilated pupils.

Field of Vision.—If the visual field is reduced the cause may be hysteria but is generally due to some organic disease. The reduction may be general, regular or irregular, on one side only, or over the whole peripheral field or half of one, or both may be lost (*hemianopia* or *hemianopsia*). The field for colours sometimes diminishes sooner than that for form and gives early indications of some diseases.

Headaches and Eye-pains.—While some headaches, *i.e.* those over the brows, between the brows, and at the temples, very frequently indicate refractive errors or muscular defects which can be corrected by lenses, it must not be forgotten that headaches are symptoms of many other troubles. Especially should it be remembered, by the optician, that refractive errors cannot be considered to be the direct cause of pain at the top, or at the back of, the head. Pain within, or behind the eye, may be merely the result of uncorrected refractive error or muscular trouble; severe pain, however, within, at the top, around or at the back of the eye, or shooting down the nose, point to more serious conditions. Sharp stabbing and throbbing pains or pain within the eye, are suspicious symptoms even if unaccompanied by others. Tenderness of the eye to touch is a bad symptom.

Photophobia and Lachrymation are symptomatic of disease quite apart from refractive errors. The latter may be caused by excessive secretion or defective lachrymal apparatus. There may also be dread of exposure to air, wind or light.

Cataract—literally, a curtain—is the condition which results from opacity of the crystalline or its capsule. It may be due to injury, to general or local disease, or to a change in the nutritive fluid leading to opacity of the lens substance. It may occur at any age, even at birth, but generally appears in old people and is a symptom of senile degeneration. A cataractous eye should always be examined by the medical man for, not only is its treatment surgical, but it may well be a symptom of other disease and, further, inspection of the fundus before the cataract is ripe is of extreme importance with respect to the prognosis of vision after operation. Smoked glasses, by inducing dilatation of the pupil, may be useful in some cases of cataract confined to the centre of the lens. This forms the variety which some profess to cure, without operation, by instilling atropine, which dilates the pupil, so that the person sees better and imagines he is being cured.

A person may have senile cataract without, of necessity, being very old; thus it may appear as early as 40 years of age. In general the progress of the disease is very uncertain, and may be rapid, or slow, or alternately the one and the other.

The general indications of cataract are:—

Reduction in visual acuity.

The ophthalmoscope, especially if used at about 20″ without the condenser, shows dark peripheral striæ, or a dark centre on the red reflex; but the media, in incipient cataract, are sufficiently transparent to allow of the fundus being clearly seen.

Focal illumination shows a dense white, grey or brown appearance of the pupil, opaque patches, opaque spicula or central opacity. True opacity must not, however, be confused with the normal milky appearance of an old crystalline (vide The *Pupils* and *Defects of the Normal Eye*).

Reduction of H. or Pr. or acquisition of M. in elderly people (vide *Second Sight*). Sometimes there is rapid increase of Pr.

It is more than probable that the advent of senile cataract is greatly retarded by preventing eye-strain, *i.e.* by correction of any optical error.

Second Sight is a name applied to that condition where a person who, being Em. or H. as well as Pr., has been using a Cx. correction for reading and finds that he needs weaker lenses and finally none at all, for that purpose; a species of acquired M. is set up. The ability to discard Cx. reading glasses is due to increased power of the Crys. which results from the progress ot senile cataract. Since the progress of cataract may be rapid, the ability to read without glasses may be of short duration. Again, the progress may be very slow and fair sight may be retained for some years.

Dislocation of the Lens is characterized by loss of Ac. and a totally or partially tremulous iris; a crescent—the edge of the Crys.—may be seen cutting the pupil.

Tobacco and Alcohol Amblyopia.—Here the visual acuity and perhaps the field is reduced, but indirect is relatively better than direct vision. Colours are badly seen, a sovereign and a shilling being confused, and a characteristic symptom is when a small red or green disc is seen better by *peripheral* than by *central* vision. Abstinence from tobacco is essential. The central colour-blindness may last several months and is occasionally permanent, but the colour usually returns along with vision for form. Oculists are not all agreed as to whether tobacco alone, without indulgence in alcohol, can cause it. Alcohol alone may bring on a form of amblyopia characterized by a reduced field of vision. In cases like these, it is essential to remember that mere abstinence from tobacco or alcohol does not suffice for a cure; medical treatment is needed in addition. Further there may be complications and, finally, the symptoms may be indicative of other diseases.

Amblyopia and disturbance of vision may also result from the excessive use of tea, coffee, etc., and disease, amblyopia, visual and colour defects can occur from drugs and poisons such as quinine, iodoform, mercury, lead, arsenic, and phosphorus taken internally, absorbed or inhaled. Workers in perfume, explosive, rubber and other factories are liable to be affected.

Paresis and Paralysis of Ac.—The former is a partial, and the latter (cycloplegia) is a complete loss of accommodative power. The cause may be traumatism, disease or poison. Apart from the medical treatment required, there is needed the very weakest Cx. lenses which allow of reading being done. These lenses must be gradually reduced in power as the accommodative action becomes restored and should be supplied *only* by direction of the medical man.

Iridoplegia is paralysis of the sphincter iridis.

Albinism is the absence of normal pigmentation. The hair, brows, lashes, etc., are white, or nearly so, and the irides are translucent, causing the eyes to appear pink. There is sometimes nystagmus, and photophobia is invariably present. Sight is defective owing to the intensity of illumination transmitted through the irides and internal reflections due to the choroidal pigment being largely absent. Smoke glasses are needed.

Nystagmus is a condition where there is continuous involuntary movements of the eye; the oscillations may be rotary or vertical, but are generally horizontal. They seem to be caused by an unconscious effort to obtain a clearer image by so moving the eyes that constantly different cones may be stimulated. The action is generally binocular and is met with in albinism, corneal nebulæ, in some diseases such as retinitis pigmentosa, in nervous complaints and in conditions where, owing to defects at the macula, fixation is impossible. Another cause—as in miner's nystagmus—is spasm of the vertical or oblique muscles due to continued use of the eyes in an unnatural position, as when turned upwards directly, or obliquely. In some cases the sufferers do not appreciate the movement, the field of vision remaining steady, but in others the nystagmus is a source of great annoyance.

Conical Cornea.—In this condition, the cornea assumes the shape of a blunted cone, or, rather, an exaggerated hyperbola, and resembles a central high M. combined with irregular As., the latter being very frequently augmented by asymmetry of the cone itself.

It is an acquired condition due, it is supposed, to softening or defective nutrition of the central layers of the cornea; it is usually found in females of weakly constitution, commencing at about 15 to 20 years of age, and is comparatively rare in males. It is generally binocular and about equal in the two eyes, but there are exceptions to this. Its progress is erratic; sometimes it increases regularly for a few years and then becomes stationary; while at others there are considerable periods of quiescence between periods of progression. In very advanced cases the central portion of the cone may become opaque but the cornea has rarely been known to be ruptured however great the thinning and projection.

Conical cornea is almost invariably accompanied by a form of *regular astigmatism* due, not to the hyperbolic curvature, but to the obliquity of the axis of the hyperbola to the visual axis. In the early stages it is difficult to diagnose and may be mistaken for M. especially as improved V. results from the use of Cc. sphs. alone or combined with cyls. When the condition is advanced, lenses only partially improve vision. Any optical treatment would be therefore the same as suggested for irregular corneal As., and in this condition considerable visual benefit is very often derived from stenopæics, or half opaque discs, combined with the most suitable lenses. By means of stenopæics good and useful vision may often be obtained for close work, even when the defect is advanced and vision much reduced for distance. One of the peculiarities of conical cornea is that equally good vision seems to accrue from the use of many different powers of lenses, but cylindricals are usually an aid, although not necessarily with stenopæics, and they may be either Cx. or Cc. The use of concave hyperbolic lenses of varying depths and curves has been tried but, in practice, the slightest departure of the axis of the cornea from that of the hyperbolic lens causes the latter to be worse than useless. Medical attention is needed, not only in the later but also in the incipient stages of this defect; operative treatment may become necessary especially if the apex of the cone becomes opaque as it frequently does in advanced cases.

It is said that reading and close work should not be allowed as the strain of accommodation tends to aggravate the trouble. Except on the general principle that a defective organ should be rested, there does not seem to be any reason for this, but it is certain that *stooping must be entirely avoided* since it would tend to increase the defect, while strict attention to hygiene, improved ventilation, and outdoor occupations assist in arresting its progress.

Conical cornea can be determined by the following :—

(1) Inspection of the corneal profile reveals its abnormal shape if the latter be sufficiently pronounced.

(2) Light reflected from the cornea is stellated.

(3) The image of a small square of white paper reflected from the cornea is seen distorted.

(4) With the placido disc the rings are seen markedly distorted and bunched up towards the centre; the images vary to a marked degree on changing the direction of view and in this respect conical cornea differs from irregular As.

(5) With the ophthalmometer the images are distorted.

(6) With the retinoscope, on ordinary rotation, the effect is indefinite but if the mirror be given a rotary motion, there is seen a characteristic swirling appearance of the shadow.

(7) With the ophthalmoscope the appearances are also indefinite and vary with the direction of view. There may be a red central portion with a dark ring around it, or the centre may be dark with a surrounding light ring. Some of the light reflected from the mirror enters the eye and some does not.

Other Conditions.—The attention of the optician is drawn specially to the following three dangerous ocular diseases, because frequently those suffering from them, in the incipient stages, present themselves to an optician for glasses. Surgical aid is urgently required so that, should they be suspected, an oculist must be *at once* consulted, time being the essential factor in the saving of the sight.

Symptoms marked * are of paramount importance.

1. *Glaucoma.*—A pathological condition resulting from abnormal intraocular tension.

Pain in globe, or around orbit and head and down the side of nose.
*Dilated, irregular or vertically oval pupil.
Sudden or excessive presbyopia.
Redness of, or pink zone adjoining, the cornea.
*Coloured rings seen by subject around artificial lights.
*Reduced visual field—this would probably be the first symptom of all.
*Increased hardness (tension) of globe.
*Cornea nearly or quite insensitive to touch.
Cornea dim; aqueous not clear.
*Misty sight.
Ophthalmoscope shows cupping of the optic disc.

2. *Iritis* and *Cyclitis.*—The former is inflammation of the iris, the latter of the ciliary body.

A pink zone, in the sclerotic, surrounding the cornea.
*No response or sluggish response of iris to light.
*Unequal contraction of the two pupils (with equal luminosity).
Irregular contraction of a pupil.
Unequal colour of the two eyes (the one being dull or muddy).
*Fibres of iris indistinct and sodden.
*Muddiness of the aqueous.
Occasionally sharp stabbing or throbbing pain in, at top, or at back of eye.
Photophobia, lachrymation, conjunctivitis.

3. *Sympathetic Ophthalmia.*—Disease of the good (or sympathizing eye) where the other (or exciting) eye has been injured or is completely or partially blind.

*Pain in the exciting eye, especially on touching it when closed.
*Sight becomes indistinct for a short interval now and then, that is intermittent or flickering sight of the sympathizing eye.
*Difficulty with accommodation, *i.e.* variable or receded P. P. or undue Pres.

There may be also any of the symptoms given for iritis and cyclitis of which sympathetic ophthalmia is a form.

In *all* cases where one eye is blind and the good one is giving trouble, or if an eye is *tender on pressure*, refer the case to a medical man *at once.*

The Optician's Duty with cases of disease or suspected disease is simply to inform his customer that, in his (the optician's) opinion, it would be advisable that a medical man be consulted to make sure that there is nothing more than an optical trouble. Should the customer demur, the optician can only state that he considers this to be the proper course and that, either he will not supply any glasses, or will do so only at the special request of the client. On no account should he state that there is a disease present, much less should he say what disease he suspects. He might very well be mistaken in either or both which, besides giving his customer unnecessary alarm, would not redound to his credit. When the advice has been given that an oculist be consulted that fact should invariably be entered in the record book.

Irides and Pupils.—The iris lies within the aqueous (*vide* Chapter I.), and is steadied by contact of its pupillary margin with the crystalline. It corresponds in shape and function to the iris diaphragm of a photographic lens, regulating by its contractility the amount of light admitted to the interior of the eye and reducing the aberrations. Absence of the Crys. is characterized by a tremulous iris.

Colour of Iris.—The pigment of the iris gives to the eye its distinctive colour; if deficient it appears grey or blue, running through all shades of hazel and brown as the pigment increases. The iris is never of uniform colour throughout, but is more or less mottled, the predominant colour being that to which the distinctive name is given. Most children of European descent—especially in northern latitudes—are born with blue or steel-grey irides, the colour generally becoming darker or brown as the child gets older. Highly pigmented and, therefore, very dark brown irides are habitually found among coloured races and among whites who have lived for generations in tropical or semi-tropical climates where more protection is needed from the intense light of the sun. The iris of an albino contains so little pigment as to be translucent and under favourable conditions the red colour of the fundus may be seen through it, giving to the eye a characteristic pink colour. Photophobia may result from imperfect pigmentation, the light penetrating the more or less translucent iris; this is most pronounced in albinism where the pigment is largely absent.

Dark blue and violet eyes seem to be more liable to asthenopia than those with light brown, light blue and hazel irides; light blue and grey eyes generally have excellent visual acuity but dark brown ones better endure intense light.

The pupil appears black because light issuing from it tends to follow the direction of the entering rays and therefore fails to enter an observer's eye unless the latter be situated in the direction of the emergent rays reflected from the fundus. The returning rays can be received by looking through a hole in the centre of a mirror adjusted to reflect a beam of rays into the observed eye, such an arrangement constituting the principle of the ophthalmoscope. If, however, the pupil is widely dilated a position can sometimes be found where the observer can receive, without an ophthalmoscope, a sufficient amount of reflected light to perceive the colour of the fundus of an observed eye.

Although the pupil normally is black, it presents a greyish appearance in old age due to fluorescence of, and reflection from, the crystalline which has become less transparent. This is often mistaken for cataract but can be distinguished from it by the fact that the fundus is ophthalmoscopically visible and vision comparatively good. The normal pupil is round, but in astigmatism it is sometimes found slightly elliptical, the long diameter corresponding to one of the principal meridians. It may be distinguished from an irregular or elliptical pupil due to adhesion by its power of equal dilatation in every direction which is not the case when there are adhesions of the iris to the lens capsule or cornea. An elliptical or abnormally shaped pupil may result from a blow on the eye, or injury or wound of the iris. The centre of the pupil coincides with neither that of the iris nor of the cornea, but lies slightly to the nasal side of the centre of both and its position therefore approximates to the visual line.

Variations of Pupil.—In a bright light the pupil contracts immediately and becomes larger as the light is reduced; in total darkness it is widely dilated. In average light intensity the pupil is of medium size—say from 3 to 5 mm. in diameter. When stimulated by light the sphincter iridis contracts, thereby tending to close the pupil by overcoming the elasticity of the radiating fibres and stretching them towards the centre. This is not a direct, but a reflex stimulus from the light incident on the nerve terminals of the retina causing an involuntary contraction of the sphincter pupillæ. Certain drugs termed *myotics*, as eserine, pilocarpine and opium, cause contraction, while others termed *mydriatics*, as atropine, homatropine and cocaine cause dilatation of the pupil.

A small pupil tends to modify defective vision due to ametropia; in old age the distant vision of a myope, apart from other reasons, is improved by the lessened size of the pupil and a presbyope can read without glasses if pupillary contraction is stimulated sufficiently by direct light. Dilated pupils impair vision; thus when they are dilated and accommodation suspended by a mydriatic one can read with the aid of suitable lenses, but vision remains impaired to a certain extent owing to the peripheral errors of curvature brought into play by the increased size of the pupils. As a rule myopes see much worse at dusk than during the day, due to the fact that their pupils dilate and the sharpness of the retinal images is then still more reduced. Asthenopia and photophobia are also commoner when the pupils are large. Although they act independently, there is an intimate connection between the sphincter of the ciliary and that of the iris, so that when the eye accommodates the pupil contracts. When the eye is adjusted for distance accommodation is relaxed and the pupil dilated, permitting an increased quantity of light to enter the eye. If the iris were inactive, the altered form of the crytalline in near vision would probably make the pupil larger, owing to the forward pressure of the lens on the pupillary margin of the iris. The pupils are usually large in myopia and small in hypermetropia, due no doubt to habitual relaxation of accommodation in the former and accommodative effort in the latter. They are comparatively large in youth and small in old age but why this should be seems difficult to explain; the contraction of the pupils during sleep and their dilatation under strong emotion is also apparently inexplicable.

The pupillary mobility can be tested by turning the eyes alternately towards and away from a bright light, or by bringing a candle flame in front of the eyes, when the pupils should respond equally to altered illumination. If one eye be occluded the pupil immediately dilates, causing sympathetic dilatation of the other but sometimes to a lesser extent. Old age considerably lessens the pupillary mobility which is perhaps naturally to be expected. Normally the pupils are of equal size, and although slight inequality is not unusual, any marked difference may point to disease unless, indeed, it is due to an intentional or accidental instillation of some drug in the one eye.

Polycoria is that condition in which there is more than one pupil, the commonest cause being detachment of the iris from the sclero-corneal margin.

Coloboma of the iris is a congenital absence of a part of it, but the sphincter pupillæ continues along the edge of the cleft and usually the pupil reacts to light. A condition similar as to appearance results from an iridectomy but here the sphincter is absent from the edge of the cleft and the pupil does not respond.

Aniridia or Irideremia is a congenital absence of the iris and is usually binocular; the resultant photophobia and spherical aberration render vision very defective.

Light Divergence.—The angle of divergence of light entering the eye varies directly with the size of the pupil. Let δ be the angle of divergence, p the diameter of the pupil, and d the distance of the object. Then $\tan \delta/2 = p/2d$ or, approximately, $\tan \delta = p/d$.

If p be taken as 3·5 mm. and d as 1 m. we have $\tan \delta = 3{\cdot}5/1000 = {\cdot}0035 = \tan 12'$. Then if the angular divergence of light from an object at 1 m. is $12'$ for the average pupil, that from any other distance may be taken as inversely proportional; thus when $d = 6$ m., $\delta = 2'$; when $d = 20$ cm., $\delta = 1^\circ$ and so on.

Irides of Animals.—Nearly all mammals have yellowish-brown or dark brown irides, but birds have brilliantly coloured ones—scarlet, green, golden-yellow, blue, etc.—which often harmonize with the colour of their feathers. Some animals possess a very high degree of pupillary activity, the pupil of a cat's eye being reduced to a slit in bright sunshine while at night, or in a dull light, they are so dilated that the irides become almost invisible. So large do the pupils of cats, and other feline animals, become at night that a light behind the observer renders the fundi visible; this gives rise to the popular idea that animals eyes are self-luminous. A circular pupil can never entirely close, whereas an oval pupil can, as in the cat. Hence the latter may turn its eyes towards the sun without any fear of injury which an animal having circular pupils could not do.

According to Lindsay Johnson, in some mammals such as the seal and sea-lion, the iris contains striped voluntary fibres which enable the animal to open or close the pupil at pleasure, to give clear vision both in and out of water, but in man the iris cannot be altered voluntarily. In fishes the iris is quite immovable and the pupil therefore fixed.

CHAPTER XIV

COLOUR AND COLOUR VISION

Composition of Solar Light.—Solar light, which is white, can be resolved, by dispersion, into seven distinct colours, viz., red, orange, yellow, green, blue, indigo, and violet. Some authorities omit indigo and consider the spectrum to consist of six main colours, and some even omit the yellow, which colour indeed occupies but a small space in the spectrum. The combination of these colours in correct proportion produces white light.

The sensation of red is produced by comparatively long waves of low frequency, the sensation of violet by short waves of high frequency while the remaining colours are produced by wave lengths and frequencies between these two limits.

Cause of Colour.—Ethereal waves of certain length and frequency always produce the mental sensation of a definite colour in a person of normal colour perception. Whether the length of the wave or its frequency, or both, give rise to the definite sensation and whether the retina or the mind differentiates between the various waves, are points not yet settled.

Complementary Colours.—All the spectrum colours are not required to produce white light; it suffices if any two which are complementary to each other are combined. Hence a complementary colour may be defined as that which, when united with another, produces white light.

SPECTRUM COLOURS AND THEIR COMPLEMENTS.

Spectrum Colour.	Complement.
Red.	Green-blue.
Orange.	Blue.
Yellow.	Blue-violet.
Green.	Purple-red.
Blue.	Orange.
Indigo.	Orange-yellow.
Violet.	Green-yellow.

Primary and Secondary Colours.—There are six or seven distinct colours which can be identified in the solar spectrum, but it was shown by Young, and confirmed by Helmholtz, that every shade of colour in nature could be obtained from the mixture of red, green and violet in certain proportions, whereas these three colours cannot be produced by mixing others. For this reason they are called *primaries* and the other spectrum colours are called *secondaries.* Thus red and green, in varying proportions, produce orange and yellow, while green and violet produce blue or indigo. Red and violet produce purple which, however, is not in the spectrum.

Brightness of Colours.—In a prismatic spectrum the red appears brighter than the violet because the former is more crowded together while the latter is spread out. This is not the case, to the same degree, in a diffraction spectrum where the central colour is yellow, the remainder of the spectrum being of about equal length in each side. The brightest part of the spectrum to the human eye is the yellow and, in general, the intensity rises rapidly from zero, at the extreme red, to the yellow and then, dropping off again but more slowly, to zero at the extreme violet.

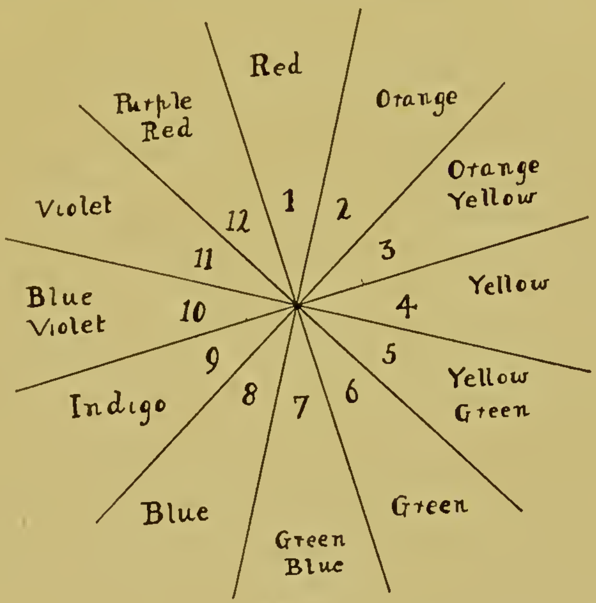


FIG. 74.

Colours in Pigments.—The primary colours in pigments (paints or colouring matter) are red, yellow, and blue; any other colour is obtained by mixing two primaries. The actual tints of the primaries are not those usually associated with their names, except in the case of the yellow, which is fairly pure; the primary blue tends towards green, and the red towards purple, and these would be better described as peacock blue and rose red respectively.

The primaries and their complements are shown in the above diagram, from which it will be seen that *the primaries of pigments are the complements of the primaries of light.* Thus 1, 6 and 10 are the primaries of light and 4, 7 and 12 are the primaries of pigments. The complement of a primary colour is that secondary colour which results from the mixture of the other two primaries. The complement of a secondary colour is that primary colour which is not contained in it.

Mixing Pigment Colours.—The fundamental difference in the results obtained by mixing spectrum lights and pigment colours lies in the fact that the former is an *additive* and the latter a *subtractive* process. In other words, the coloration of mingled lights is due to the *sum* of the separate wave-lengths, while the resultant colour given off by the mixture of pigments is that remaining after each pigment has *absorbed* a certain wave or series of wave-lengths. The tendency of added lights is to give increased illumination and to approximate to white, while with pigments a mixture tends towards black. Thus, when the primaries of light, *i.e.* red, green and blue-violet are mingled—projected, say, from three separate lanterns—the white screen reflects all three impartially to the retina where their superposition produces the sensation of white. With pigments, however, the final colour is due to that remaining after each pigment, in a certain mixture, has absorbed from the incident white light its own complement. In this way the primary colours of pigments are those capable of absorbing the three primaries of white light, *i.e.* red, green and blue-violet, whose respective complements are green-blue (peacock blue) purple-red, and yellow. These last three are therefore the primaries of pigments because, when mixed in the right proportion, they (theoretically) produce *black.* In practice, however, owing to the inevitable impurities of pigments and the impossibility of securing the correct proportions, the result is a dark grey. For the same reason it is impossible accurately to match the spectrum colours by means of pigments and this is especially the case towards the violet end. In fact we cannot imitate spectrum violet by any known pigment or combination of pigment colours. In some instances, therefore, the effect of a pigment mixture may be surprisingly different from the result of mingling lights of corresponding colours. Thus blue and yellow pigments combined make green. The blue pigment reflects violet and green, the yellow reflects red and green; if the two pigments be mixed, there is reflected a certain quantity of violet and red and a double quantity of green. The red, the violet, and a portion of the green combine to form white light, so that there is a residue of green which gives the nature of the colour to the mixture of the two pigments; or, more properly, the blue absorbs red, the yellow absorbs violet, so that the green only remains to be reflected. If, however, blue and yellow lights are mingled in the right proportion on a white screen they cause the sensation of white.

As another illustration, red and blue-green are complementary colours which, added to one another, produce white in the case of coloured lights (additive effect) but neutralize each other, *i.e.* produce (theoretical) black in the case of pigments (subtractive effect). The additive effect in the case of light can be roughly imitated by painting yellow and blue sectors alternately on a disc which, when rapidly rotated, gives the impression of white if the proportions of colour are correct. Here the yellow and blue alternate so rapidly on the retina that the sensations caused by alternate sectors are mingled and give rise to the sensation of white. The experiment must, however, be carried out in white light, but even then the effect is generally far from pure owing to the muddiness of the pigments.

Newton, from experiments, gave the best sizes of the sectors of a disc, consisting of reproductions of the seven principal spectrum colours, to produce the sensation of white. The values are approximately as follows :—

Red 60° Yellow 55° Blue 55° Violet 60°
Orange 35° Green 60° Indigo 35°

By increasing the number of sectors, and repeating the seven spectrum colours in the above proportions all round the disc, a still better white is secured.

Colours of Bodies.—A substance is said to be of certain colour when it reflects, or transmits, rays of certain wave-lengths and absorbs the rest of the spectrum. Thus an object which absorbs the violet and green and reflects the red waves, appears red. If it absorbs red waves, and reflects green and violet, it appears blue. A green body absorbs all but the green waves and one orange in colour reflects red and green, but absorbs violet. The colour reflected by a body is usually the same as that which it transmits, but some bodies—termed *dichroic*—transmit the complementary colour to that which they reflect. Dark colours reflect little light and slight differences between them are hardly appreciated in dull illumination; similarly, light colours reflect much light, and slight differences are hardly noticed in very bright illumination. All colours lose their distinctive hue in proportion as the light reflected becomes reduced. Thus, with dull illumination, all colours appear dark grey.

A body reflecting light of all wave-lengths is called white; a body having affinity for all colours, so that all are absorbed and none reflected, is called black. No body, however, is of a substance so chemically pure as to absorb entirely or reflect all the incident light. An absolutely black body does not exist in nature; even those coated with lamp-black and soot reflect some light, which renders them visible and allows of their form and solidity being recognized. Similarly there is no object which reflects all the light it receives ; pure, fresh snow, which is the whitest of all bodies, absorbs some 30 per cent. of the light it receives.

Colour is a quality of the illuminating light itself, as well as of the body which reflects it. In order to appear of a certain colour, the object must receive that colour in the light and reflect it, at the same time absorbing all the other colours. White, grey and black are really varying degrees of luminosity, the only difference between them being in the total amount of light reflected. In all three the absorption is the same for all colours, *i.e.* there is no *selective* power as with coloured bodies, but the extent of the absorption varies in the three cases.

Qualities of Colours.—Colours in pigments possess three qualities, viz., tone, brightness and purity. *Tone* or *hue* is that quality which differentiates between the various colours—say red and orange; it depends on the wave-length. *Brightness*, *intensity*, or *luminosity* is that quality which represents the strength of a colour and depends on the amount of light reflected; one which reflects little light is a dark colour, and one which reflects much light is a light colour. *Fullness*, *saturation*, *tint* or *purity* is that quality which represents the depth of a colour; the less the admixture of white or black the purer is the colour. Red mixed with white forms pink, whereas red mixed with black makes a kind of maroon: yellow and orange become straw and brown according as they are mixed respectively with white and black. Thus we say that yellow or orange is a pure colour, while straw and brown are impure.

Coloured Bodies and Lights.—The real colour of a body is that which it exhibits in white sunlight; it often appears of a different tone in ordinary artificial light. This is due to the fact that some particular colour usually predominates in artificial light, and therefore the mental standard of white is temporarily shifted towards that colour. Thus ordinary gaslight—not incandescent—contains an excess of red and yellow, while blue and violet are the prevailing colour in the electric arc. Painting and matching colours is always difficult in artificial light, and some blues and greens can barely be distinguished by gaslight and still less by lamp or candle-light. The nearer the colour of a body approaches to that of the illuminant the whiter will it—the body—appear; on the other hand should the colour of the body be complementary to that of the illuminant it will appear darker than it would if viewed in white light. Should the light be of a colour exactly corresponding to that which the body absorbs, none will be reflected and the body will consequently appear black. Of course a white body seen by coloured light is really coloured although it is generally interpreted mentally as white, and it certainly is so accepted if the coloration of the luminant be not excessive.

All colours are profoundly modified when viewed through coloured glass, as the reader can prove for himself. If the coloured glass absorbs the rays reflected by the body, the latter appears black; it appears white, or at least indistinguishable from white, if the glass is of the same colour. Here the colour of the glass is temporarily the mental standard of white. Thus red letters on a black ground, viewed through a green glass of the proper shade, become invisible (as in the "friend" test), the red rays reflected or transmitted by the letters not traversing the glass. Red letters on a white ground, seen through a red glass of proper shade, similarly become invisible, the whole being of uniform tint and on looking at a green object on a red ground through a piece of green glass, one sees an apparently white object on a black ground.

Shadows.—A shadow is cast by a body when it intercepts the light from a source, so that a dark space may be seen on the wall or ground where the shadow is. The latter, resulting from the interception of white light, appears grey or black because less light, or none at all, is reflected from that area of the wall or ground occupied—if one may use the term—by the shadow.

The shadow resulting from the interception of a coloured light appears to be of the colour complementary to that of the light. This occurs because the illumination of the ground is coloured and the light reflected from it is mentally taken as the zero of the scale of colour sensation and the darkened space, *i.e.* the shadow, then appears complementary to that light. If two shadows are cast—the one by a red and the other by white light—the shadow resulting from the red light appears greenish as the result of contrast with the reddish ground and with the other shadow which is tinged with red since it receives only that coloured light.

Superposition of Coloured Glasses.—When two coloured glasses are placed together we have an example of the subtractive process similar to that seen in the mixture of pigments. The first glass eliminates from incident white light all but its own colour and, if the second glass is the same as the first, no further alteration takes place except a slight reduction in intensity due to absorption. If the second glass is not of the same colour as the first, a certain amount of absorption by *subtraction* takes place in the second and the more nearly complementary are the two glasses the more nearly will the whole of the incident light be cut off. For example, if a blue-green and a red, or an orange and blue glass, be placed together, the light transmitted by the one is absorbed by the other and the combination rendered opaque. Cobalt glass transmits red and blue, ordinary green glass transmits blue and green; on the two being placed together original white light transmitted appears blue, since the blue is transmitted by each but the remaining colours absorbed.

Sensitivity of the Eye to Different Colours.—The human eye is most sensitive to yellow whether seen in the spectrum or by reflected light. If the colours are equally intense, yellow and red can be seen farther than others. Generally speaking, as a characteristic and recognized colour, red is the most persistent of all; owing to its long wave-length it freely penetrates haze, fog or smoke glass, while the penetration of other colours follow more or less in the order of the spectrum. For this reason red is employed as the danger signal, while blue-green is employed as the contrast signal on railways and ships. Similarly the sun appears redder at sunrise and sunset than at midday, and also in fog, the blue-violet end of the spectrum being absorbed. Green, which prevails in nature, fatigues the eye least of all the colours; then blue-grey, purple, yellow, orange and red, the last being the most fatiguing. For this reason billiard-tables are covered with green cloth and blinds are usually painted that colour. The sea and sky are blue, red and orange occurring only in patches, or occasionally as at sunset; the eye is able to bear those colours best which are most widely distributed in nature and most likely in consequence of it. With respect to light, in general it is more satisfactory the nearer it approaches white, but if coloured lights are used for illumination they should be pale and largely diluted with white. Thus pink and pale orange, or pale green, are pleasant but the same colours pure and saturated would prove extremely fatiguing to the sight.

Sensitivity to Intensity.—Although the eye is well adapted for distinguishing between the tints of two bodies, it is very defective in detecting the difference in *intensity* between two differently coloured sources. With practice we can observe a difference in the hue between two colours having only a small difference in wave-length, but we generally fail to get within even an approximate estimate of their relative intensities. According to Fechner, the eye is capable of detecting a difference of 1 per cent. in two adjacent white surfaces of average illumination, but with colours an estimate of such accuracy is quite impossible and the difficulty increases as the colours chosen are opposite in nature, *i.e.* complementary. Thus if a red and a green source be taken, their difference in *colour* is most apparent, except to a colour-blind person, but practically everyone would make large errors as to their relative *intensities*. It is, however, possible to balance photometrically the intensities of any two coloured sources, but even then another difficulty arises and that is the change in sensitivity of the eye to the various hues as their intensity is uniformly varied. This phenomenon was first discovered by Purkinje and afterwards elaborated by others.

Purkinje's Experiment.—The greater the power of a source, as measured by a photometer, no matter what its colour may be, the more nearly does it approximate to white. Conversely as the intensity is lowered all colours approximate to black but the approximation is not the same for all. Thus the sun viewed through glass of any colour appears whitish while if its image be projected by means of a convex lens through any coloured glass, the focus will also appear nearly white provided the density of the glass be not excessive. Purkinje, in experimenting with feeble illumination, discovered that vision for the shorter waves was more persistent than for the longer ones. If two parts of the spectrum, say red and blue, be taken and rendered equally intense, the red will appear to most people as being the brighter; but as the illumination is lowered the red fades more rapidly than the blue so that, when the red has altogether disappeared, the blue is still visible as pale grey. Purkinje's phenomenon is thought to be confined to the rods and visual purple because it is more marked as the distance from the macula increases—that is, as the proportion of rods to cones increases. Similar phenomena may be noted with coloured bodies, *e.g.* when red and blue paper are viewed in light sufficiently feeble to render the red black, the blue will still be visible as greyish.

Colour Fatigue and After-Images.—If the retina be subjected to prolonged exposure to light of a certain colour we have the condition known as *retinal fatigue*, the immediate effect of which is to cause temporary blindness for that particular colour. Some little time elapses before the retina recovers its normal sensitivity but recovery is generally hastened by blinking and moving the eyes about. This phenomenon may be easily demonstrated in various ways. Thus if we stare intently for a few minutes at a row of letters coloured alternately red and green and then suddenly transfer our gaze to a white or grey surface such as a ceiling, the outlines of the letters will be seen but in reversed colours, those that were originally green appearing red and *vice versa.* Or we may take as an object a blue paper cross on a yellow background, the after-image of which appears as a yellow cross on a blue ground and so on. The nerves, on saturation by a colour, are apparently rendered abnormally sensitive to its complement, but actually this is due to their inability to respond to the original colour after prolonged exposure (vide *Visual Phenomena*, Chapter XV.). By means of a coloured glass, we can thus render the eye temporarily blind, when it is removed, for that particular colour; but it should be noted that, with the glass kept in position, the colour to which the eye is artificially blind is complementary to that of the glass (vide p. 249).

The Mental Standard of White.—Saturation of the retina by any colour causes the standard to be displaced; the mind accepts that colour as the zero, just as white is considered to be the zero in ordinary circumstances. Thus, if on a coloured sheet a very small piece of white be placed, the latter appears of the complementary colour to that of the other. If the sheet be red, this presently appears more nearly white, and the white then appears bluish-green. It would appear that one mentally conceives as white that body which reflects most light, and, generally, that a white body is white whether seen by sunlight or coloured artificial light, although actually the appearance would be quite different if a comparison were possible. We do not, in reddish gaslight, take white to be other than white, for our colour standard is then altered for the coloured light. It is for this reason that a red body on a white ground, seen through a red glass, is indistinguishable from the ground, since they both appear the same whitish colour.

Perception of Black.—A black object is seen because a retinal image is formed of the surroundings, *i.e.* the mind appreciates the gap in the visual field. Nevertheless a black body does radiate some light and most likely it is appreciated as an intensely dark grey, *i.e.* a combination of black and white elements, for the difference between grey and black is merely one of degree. Therefore black may be considered a colour in a certain sense, for if an object reflected no light at all, it would be invisible, whereas a so-called black body is mentally appreciated. Thus a solid body, black in a popular sense, is seen, not as a flat gap in the visual field, but as a body having three dimensions. According to Hering black causes a distinct sensation, the complement of, or opposing sensation to, white. The visual sensation one experiences, in a totally dark room, is quite different from that of an image projected on the blind spot of the eye. In the former case, one undoubtedly perceives the darkness; in the latter case, one does not perceive anything, and therefore one is unconscious of the gap in the visual field. We must therefore distinguish between the absence of all light stimulation on a portion of the normally active retina, capable of conveying a colour sensation to the brain, and absence of the *capacity* to so convey it.

Colour Vision.—The usually accepted interpretation of colour vision is that known as the *Young-Helmholtz theory.* According to this theory the retina possesses three sets of elements, each one responding to one of the three primary colours, viz. red, green, and violet. It is supposed that red light stimulates mainly the red retinal elements but also to a lesser extent the green and, to a still lesser extent, the violet. Similarly the violet retinal elements are mainly stimulated by violet light, but this also slightly stimulates the green and red retinal elements. In the same way the green elements are chiefly, and the red and violet elements slightly, excited by green light.

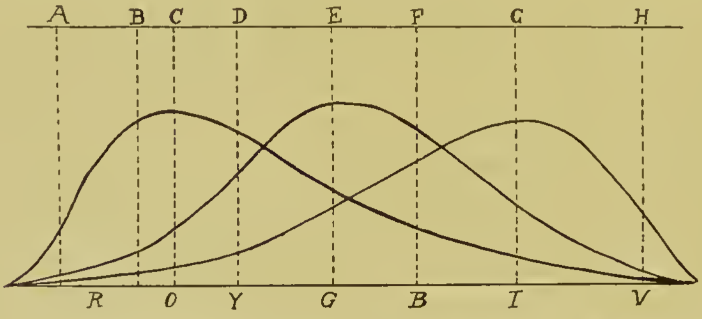


FIG. 75.—DIAGRAM ILLUSTRATING THE YOUNG-HELMHOLTZ THEORY OF COLOUR VISION.

The letters refer to Fraunhofer's lines; the height of the curve corresponds to the intensity, and the length shows the part of the spectrum covered.

Stimulation of one of the three elements produces the sensation of a primary colour; stimulation of two causes a sensation of a secondary colour; equal stimulation of the three elements causes the mental appreciation of white; stimulation of the three to varying extents causes the sensation of the predominant colour diluted with white. Absence of one or more retinal colour elements is supposed to be the cause of colour blindness.

Hering's theory of colour vision is based on the supposition that there are three pairs of sensations, viz. black and white, red and green, blue and yellow. The sensation of white results from decomposition of the black-white substance, while darkness results from its regeneration. Red or green results from decomposition and regeneration of the red-green substance and similarly blue and yellow of the blue-yellow substance. Various other theories of colour vision have also been advanced.

It is possible that some of the retinal elements, say the cones, are stimulated by all light equally, while the rods have a selective faculty, each of them being sensitive to a given wave-length only. If this were so it would explain why at the macula, where the rods are absent, the colour of a very small retinal image is not appreciated. Or it may be that the faculty of discriminating between the effects of waves of different length or frequency lies in the brain, there being different centres for colour, light and form. It is difficult to conceive that the retina consists wholly of red, green and violet elements, for if so a person blind for one colour should have a reduced visual acuity in consequence; one totally colour blind should be also totally light and form blind, but neither of these is the case.

The history of man would seem to indicate that the colour sense is progressive. The colours mentioned by ancient writers are few in number, so that it may be conceived that the perception of different colours, and shades of colour, has increased with the development of painting and the fine arts. Even to-day a person possessing the most normal colour vision cannot differentiate between closely adjacent portions of the spectrum, and one has to view fairly distant portions in order to be able to appreciate a real difference of tint. Nevertheless among dyers and milliners the sense of colour is highly developed; by training, they can distinguish fine differences of shade and hue in ribbons and dress materials which to one untrained, appear more or less the same. It is, then, not unreasonable to suppose that colour blindness is a kind of reversion to an ancestral state when the colour sense was in its infancy.

Colour Blindness, which affects about 4 per cent. of people, is due to a deficiency in, or absence of, light perception of a portion of the spectrum. Such deficiency may be very slight, it being merely the inability to distinguish certain shades of colour, or it may be very marked there being a total absence of the faculty of distinguishing between colours.

Inability to appreciate one of the primary colour results if one of the retinal elements be absent or inactive. Thus, according to the accepted Helmholtz theory of colour vision, if one has no red elements, red light on entering the eye would stimulate the green elements slightly, and violet still less, causing a sensation similar to that of feeble green light. Probably feeble red light would not be appreciated at all by one deficient of the red retinal elements. Thus, in this condition red would be indistinguishable from dull or feeble green. On viewing the spectrum, either the red end would be seen shortened or the green would extend up to the long wave extremity of the visible spectrum. This condition of red blindness is sometimes termed " Daltonism " from John Dalton who suffered from it and was the first to describe it. Or there may be absence of the green sensation, the yellow and blue meeting in the spectrum seen. Again there may be dark bands in the spectrum, the waves which normally occupy these spaces causing no retinal or mental stimulation. Total colour blindness is a rare condition in which no colours at all can be appreciated or, rather, all wave-lengths cause the same colour impression, *i.e.* there is merely variation of luminosity ; the spectrum appears as a continuous band, although it might vary in brightness in its length. Only a few cases of total colour blindness have been recorded.

If the Young-Helmholtz theory of colour vision is to be taken literally, scarcity or weakness of those elements, by which one of the primary colours is seen, would mean feeble colour sensation for that colour and the loss in the spectrum of one or more secondary colours, while their total absence or inactivity would mean the ordinary form of colour blindness. Fewness or weakness of two colour elements would mean feeble colour sensation for the two and the loss of all the secondary colours of the spectrum, while their total absence or inactivity would mean total colour blindness in the sense that the one colour properly appreciated would be the prevailing tint and would therefore constitute the standard white or grey of the person suffering from the defect. In this way we can use the Young-Helmholtz theory to account for the fact that while a person of normal colour vision can appreciate 7 or at least 6 or 5 spectrum colours, those who are colour blind can appreciate only 4, 3, 2 or even one colour in the spectrum.

Causes of Colour Blindness.—Colour blindness is, as a rule, congenital and sometimes hereditary ; it is usually binocular although cases have been recorded of a monocular affection. It can also be acquired from jaundice and certain drugs, such as santonin and male-fern ; as a rule this acquired form is only temporary. Excessive use of tobacco may cause more or less amblyopia which is accompanied, over and around the macula area, by colour blindness for red and green which does not extend to the periphery ; such colour blindness is characteristic of nicotine poisoning. Temporary colour blindness can always be caused by excessive stimulation of the retina by any one colour of excessive brightness as found when after-images are seen. In these cases the retinal elements, which were stimulated by the colour gazed at, become temporarily paralyzed by exhaustion so that a localized blindness for the colour, called a *colour scotoma*, is formed. As described in the experiment on page 245, the negative after-image of a colour, complementary to the original, is seen because the white light received by the eye stimulates two of the retinal elements only. After a few minutes rest the scotoma dies away and the lost colour returns.

Artificial colour blindness can also be caused by the employment of coloured glasses or monochromatic light, and it is instructive, if one wishes to understand something of the errors made by the colour blind, to view mixed coloured wools in monochromatic light, or through a pair of coloured glasses and attempt, under these conditions, to match the test skeins. Spectrum blue glasses are suitable for the purpose and perhaps still more so cobalt blue of sufficient depth of colour to cut out the green. Red glasses, which transmit only the one colour, would produce a condition somewhat similar to total colour blindness.

Tests for Colour Blindness.—It must be remembered that in testing colour blindness one has to deal with those who are often ignorant of their defect, or who may be unwilling to acknowledge and therefore try to hide it.

THE WOOL TEST.—The usual method of testing colour blindness is by means of the Holmgren wools, and consists of matching certain test skeins with others taken from a confused group comprising all colours and shades. The test is made in three stages and the test skeins are: (1) pale pure green; (2) reddish-purple (or rose) containing approximately equal parts of red and blue; (3) bright red. The pale green is, of all the spectrum colours, the nearest approach to white (or grey); the purple is not contained in the spectrum and the pale green and purple are complements of each other.

First Stage.—The confusion wools are mixed and placed in a heap. The light green test skein is given to the subject, who is told to select from the heap such skeins as resemble the test skein.

A person having normal vision will select only greens.

A person having feeble colour vision will select others such as greys and fawns.

One having true colour blindness will select markedly different colours, such as pinks, yellows, or blues, as well as greys, etc.

The confusion made with No. 1 test skein determines colour blindness, but not its nature.

Second Stage.—The confusion wools being again mixed, the purple skein is presented and the subject is asked to match it from the heap.

A person with normal or feeble colour vision will make no mistakes.

If he has partial colour blindness he will select deep purples.

If he has red blindness he will select blues and violets since he appreciates the blue of the test skein, but not the red.

A person having blue blindness will select reds and oranges since he appreciates the red of the test skein, while the blue does not excite his retina but, it may be added, blue blindness is extremely rare.

One who is green blind selects greys and greens, because the combination of red and blue, forming the purple, contains all the colours of his visible spectrum and is, for him, an impure white which is the same as grey; while the green, for which he is blind, appears as an impure black, *i.e.* a dark grey. Consequently purple, green and grey are similar colours to the green blind.

Third Stage.—The final test is made with the bright red test skein, and serves rather to confirm the results made with the first two skeins. The red-blind person may select darker shades, and the green blind lighter shades, both in any other colours, as green, blue, etc., besides reds. This occurs because, to a red-blind person, a red object does not appear black, nor does a green object appear so to one who is green blind. Such objects to them appear grey, because colours are never pure, but give off other rays besides the red or green respectively; also because the retinal elements are, to a certain extent, all stimulated by light of whatever wave-length.

In the Board of Trade Colour Tests for Seamen, two further stages are included, viz.:—

Fourth Stage.—A blue-purple test skein has to be matched. One who is colour blind will confuse it with blues, greens, pinks and greys.

Fifth Stage.—A pure light yellow test skein has to be matched. One who is colour blind will select, as matches to it, green-yellows, yellow-greens, pinks and fawns.

The subject is further tested in the nomenclature of colours, especially red, green and white which he has to name when presented to him.

Other Tests.—Some of those who are best qualified to judge claim that wool-matching is a very unsatisfactory test, since colour-blind persons can easily be coached up to match correctly almost any shade of wools. For this and other reasons, many other tests have been designed which involve the use of coloured glasses, letters, powders or papers; shadows cast by means of coloured lights, colours contained in revolving discs and those of lanterns, flags, etc. The naming and matching of coloured glass discs in front of a lantern, the discs being obscured by the intervention of frosted glass or neutral tint glass, is now largely used both by oculists and by the Board of Trade and is considered more accurate than the wool test. It is said that, in fact, many candidates, who pass the wool tests satisfactorily, fail to succeed with the lantern disc test. Both the lantern and wool tests are sometimes used. One of the latest forms of lantern tests is that designed by Dr. Edridge Green and made by Gowlland. With this almost any coloured glass can be switched up before the lantern and several shades of ground and neutral tint glasses added. The spectroscope and the polariscope afford delicate tests from a scientific point of view, but they are expensive, require skill to use and great intelligence on the part of the subject.

Distinguishing Colours by the Colour Blind.—A person who is red or green blind may often be able to distinguish between these two colours by the difference in their intensities. Thus a red-blind person viewing a red and a green light of equal intensities would see the green light very much brighter than the other, owing to his failing to appreciate much of that proceeding from the red light; only if the green light happens to be viewed in a fog, or in circumstances which reduce its intensity, might it appear of the same luminosity as the red.

While it is quite impossible to cure colour blindness, it is possible to train a colour-blind person to distinguish one colour from another by means of the use of coloured glasses. This is not because he sees the colours correctly; but because he learns to connect the degree of luminosity or saturation with a certain tint or colour.

Neutral and Tinted Glass.—Smoked glass absorbs equally all the component colours of white light, and when in front of the eye reduces the visual acuity to a greater or lesser degree. It does not change the colour of a body unless it is of deep tint, when it causes all dark colours to appear black and light ones grey. As already mentioned, red light penetrates pure smoke glass more than do the other waves. So-called neutral glass is, however, frequently found to be tinged with colours such as green, blue or purple. Sometimes a smoked glass which imparts a, say, distinctly green tinge to a flame seen through it will, if much thicker, or if two or three pieces be put together, cause the flame to appear bright red. A glass of distinct colour, as red or green, transmits also some of the closely adjacent tints but absorbs all the other colours. Spectrum blue blocks out the extremes of the spectrum, that is, red and orange on the one side and the violet (and ultra-violet) on the other while it transmits green-blue, green and a little yellow. Colbalt blue glass—the ordinary blue glass of commerce—has almost the contrary effect to spectrum blue; it freely transmits blue and red and if of considerable thickness excludes the yellow and green. Orange, yellow and yellow-green glass absorb the violet (and ultra-violet) light entirely and transmit mainly yellow. The ordinary white glass used for spectacle lenses has considerable absorptive power for ultra-violet light, while quartz or "pebble" is particularly transparent to it. This is strikingly illustrated by photographs of the spectrum taken through prisms of the two materials on panchromatic plates; the total length of the spectrum transmitted by the quartz is about double that of ordinary crown glass and therefore, as a protection against actinic light, quartz is singularly ineffective.

The reasons for the use of coloured glass may be found in (*a*) the condition of the eyes, (*b*) the occupation of the individual, whether permanent or temporary, and (*c*) his surroundings or the condition of nature.

It will usually be found that those who suffer from sun-glare, not only in Europe but in the tropics as well, do so on account of eye-strain. They need corrective lenses for ametropia rather than coloured glasses, and correction of the refractive error will generally cure the intolerance of light. A clear distinction should be drawn between conditions where photophobia results from excessive light and where it results from eye-strain. Further, if the retina is hypersensitive to light, the use of coloured glasses tends to make it more so. What has been said with respect to sun-glare will be found frequently to apply equally well to troubles caused by artificial lights; *i.e.* occupation or surroundings may occasion light intolerance to one and not to another, according as the condition of the eyes induces it or not. Moreover the adaptability or sensitiveness of the eyes to certain colours varies with different individuals, so that no rigid rule can be applied as to the use of coloured glasses.

With respect to conditions where coloured glasses are required, oculists sometimes order smoke glasses for patients suffering from ocular disease. Occasionally true cases of photophobia and hyperæsthesia of the retina are met with and these, as well as conditions such as aniridia, albinism, hemeralopia and nyctalopia, are benefited by the use of smoke glass. Dark glasses in incomplete nuclear cataract cause the pupils to dilate in daytime and thus more light is admitted through the clear periphery of the crystalline. Amber glass is recommended for some cases of amblyopia and spectrum blue for some diseases.

The crystalline lens of the eye, being fluorescent, is a natural, although only partial, protector against ultra-violet light. Aphakic eyes, deprived of this natural protector, may derive considerable benefit from the use of coloured glasses capable of absorbing these short waves and, if white lenses are employed, they should not be pebbles. Fluorescence is said to occur, and cause irritation in, the retina and it is also said that cataract may be induced by prolonged exposure to actinic light.

Occupation may necessitate ocular protection from light as by glass blowers, furnace-men and others engaged in callings where fire or molten metal has to be constantly viewed. For these purposes goggles fronted with thick colbalt blue, spectrum blue or smoke glass are, or should be, used. For viewing electric lights extremely deep smoked (electric) glass, which renders ordinary objects invisible or, still better, extra thick spectrum blue glass, is needed. This latter is to be preferred wherever possible since it enables the wearer to see objects around him which the deep smoked glass does not; it prevents injurious after-images even if an arc light be gazed at fixedly. Extremely deep smoke glass is required for viewing eclipses. Yellow is sometimes employed for shooting and landscape viewing, as it somewhat increases definition. Spectrum blue, amber or similar glasses are recommended for all engaged in work by electric light, since they all cut off most of the actinic waves.

The surroundings for which the use of coloured glasses is to be recommended are the seaside in sunny weather, countries where snow covers the ground and strongly reflects bright sunlight upwards, and for sandy or chalky districts, especially in the tropics, where similar conditions as regards the light are found. The brows, lashes, headgear, etc., afford natural protection for the eyes from above, whereas there is little or none from below. So long as the surrounding landscape furnishes grass, trees or dark objects to which the eyes can be turned for relief, coloured glasses are not usually required, but at sea, in countries like Canada in the winter, in the deserts of Africa and Asia and in many other tropical parts, this does not occur. For such protection, smoke glass of a suitable tint should be selected, but many people seem to prefer, and find comfort from, the use of cobalt blue, spectrum blue or yellow-green glass, especially if the glare is not strong. The Chinese for some time past have employed a pinkish tinted pebble and the Esquimaux use roughly made stenopæic slits for this purpose. Green glass is not to be recommended, while cobalt blue, although it reduces the intensity of sunlight, has little value otherwise as a light protector; the colours it cuts off, if deep, are the least injurious, and if it is of light tint it is almost entirely without effect. Spectrum blue is more effective, as a protector, since it blocks out the colours least suitable for vision. Orange, yellow and yellow-green glass are of value if only the violet and ultra-violet, which are the most injurious portions of the spectrum, need to be reduced or cut out.

If for any purpose spherical or cylindrical lenses are required of a certain selected tint, it is necessary to remember that the depth of the tint depends on the thickness of the glass, so that it should not be worked in curves if *uniform colour* is essential. Thus if a Cc. power be worked on a tinted glass it is much lighter, while a Cx. is darker in the centre than the selected test glass, but, of course, a suitable coloured disc can be selected for all ordinary powers and ordinary purposes.

Equality of tint can be obtained by employing a plano Cx. or Cc. lens cemented to a plano-coloured glass. For a sphero-cylindrical combination equality can be obtained, by cementing a thin plano-spherical and a thin plano-cylindrical to the two sides of a thin plano-coloured glass. Or if one of the components be weak, in comparison with the other, by employing coloured glass for the weaker and white for the stronger, both being planos and cemented together. In this way practical equality of tint can be obtained.

It is difficult to measure the proportion of light transmitted by coloured glass, but with smoke the following are the approximate percentages of the commercial discs; the figures given for blue are roughly estimated:

Tint.		1 or A.	2 or B.	3 or C.	4 or D.	5 or E.	6 or F.
Percentage of light transmitted ..	Smoke	60	50	30	20	10	2
	Blue	80	70	50	30	20	4

The Optical Society Standards should transmit percentages as follows :—

Tint.	1	2	3	4	5	6	7	8	9	10
Percentage of transmitted light	80	60	50	40	30	20	10	5	2·5	1·25

Since the proportion of incident light transmitted depends on the thickness of the glass, it is not easy to express variations, but approximately the transmission varies inversely as the square of the thickness. Thus a standard No. 6 *pure* smoke glass transmits 1/5 of the incident light; a second No. 4 placed behind the other, transmits 1/5 of that transmitted by the first—that is, $1/5 \times 1/5 = 1/25$ of the total light, originally incident on the first glass, is transmitted by the two together.

CHAPTER XV

PECULIARITIES OF VISION.

Defects of the Normal Eye.—The normal eye, as it is generally understood, suffers from a variety of minor defects but, in comparison with the wonderful efficiency of that organ as a whole, these are rarely noticeable except under special conditions. Of course, "defects" in this connection must be understood to exclude the ordinary errors of refraction such as H., M., As., etc., and to embrace only those inseparable from the general arrangement of the eye considered as an optical instrument.

The defects of normal vision may be considered to arise from physical, physiological or psychical causes—the first being due to errors of design or structure, the second to errors of reception and transmission and the third to errors of mental interpretation or projection. When we cannot account for what may be called optical illusions by defects of the eye itself we assign the cause to erroneous mental interpretation.

Considered purely from an optical point of view the eye has been said to be, at the same time, the most wonderful optical instrument and the worst. In general, the refracting surfaces are not spherically curved, they are not centred and the various axes are oblique with respect to each other. The media are not homogeneous and depart more or less from transparency, while the whole dioptric system is neither achromatic, stigmatic nor rectilinear in the delineation of the image.

The Cornea.—The cornea, in conjunction with the aqueous humour with which it forms a single surface, is the chief refracting body of the eye. Normally its transparency is very high, its surface polish excellent and, within certain limits, its efficiency in image formation equal to that of any artificial surface of the same power. The outer surface of the cornea (we may ignore the inner surface as being neutralized by the aqueous) is, however, spherical only over a certain area around the apex, the curvature falling away rapidly towards the scleral margin where, in addition, a considerable degree of irregularity occurs. As a whole, the contour of the cornea may be taken as similar to a hyperboloid of revolution the apex of which is replaced by a spherical cap some 3 or 4 mm. in diameter so that, except in great dilatation of the pupil, this portion only is effective in the formation of the image. The geometrical axis of the corneal surface is almost invariably oblique to the line of vision or visual axis, the latter passing out about 5° on the inner side and 3° above the apex of the cornea. Since, however, the mean centre of curvature lies close to the united nodal point of the eye—there being an interval between them of about ·6 mm.—the aberration of the cornea in relation to the visual axis is of no great consequence. The aqueous humour, or second medium, is perhaps the most transparent portion of the eye since its composition is mainly water with a small percentage of saline material in suspension.

The Crystalline Lens does not, as to actual curvature, depart much from the spherical, although during accommodation Tscherning asserts that the general contour is hyperbolic, and as a refracting medium it is not homogeneous, the density and refractive index decreasing from the nucleus outwards. As before described, the crystalline may be regarded as a strong Cx. lens enclosed between two weak concave menisci and the advantages of this construction are, first, by having the nucleus of greater density than the two menisci, the refractive power of the whole lens is greater than if it has been of the same density as the nucleus throughout; second, it facilitates the alteration in curvature of the lens in accommodation; third, it reduces spherical aberration by approximating the foci produced by the several zones of the lens. If the latter were homogeneous throughout it would need to have μ higher than that of the nucleus, say, 1·42 to 1·45 in order that its power might be the same as it actually is.

In transparency the crystalline does not compare favourably with the cornea and aqueous. Its curious structure in the form of two opposed Y.'s is liable to give rise to striæ and irregular refraction and it is said that the stellate appearance of a star, or small source of light, is due to this. The crystalline is fluorescent and its want of perfect transparency may be seen, especially in older people, under focal illumination when it appears a bluish-grey colour, and this quite apart from any cataractous tendency which greatly enhances the effect (vide *Cataract*).

The Vitreous, also from its formation, is liable to irregular refraction and generally contains a number of minute cells and bodies giving rise to muscæ volitantes although the latter may also be due to other causes.

The Retina.—In comparison with the camera, to which it is analagous, the eye suffers from two marked defects. The receptive surface or retina is not uniformly sensitive and there is, in addition, a gap in the visual field caused by the entrance of the optic nerve. At the macula we have the maximum acuity, but from that point outwards the sensibility of the retina rapidly diminishes so that, for detail, we must rely on central vision entirely. This fact, however, gives us, together with monkeys, the power of concentration absent in all the lower animals and indeed it is difficult to imagine how we should see at all with a uniformly sensitive retina unless the mental control and interpretative powers of the brain were considerably modified to suit the new conditions. As for the presence of the optic disc or blind spot, this causes no inconvenience and indeed is not perceived at all in ordinary circumstances (vide *The Blind Spot*).

Aberrations.—Chromatism and the five aberrations of form, from which ordinary single lenses suffer, are all to be found in the normal eye but, as we shall point out, their effects are not noticeable in ordinary vision.

Chromatism.—Dispersion always accompanies refraction and this occurs in the eye, the resultant chromatic aberration being about the same as that of a similar homogeneous body composed of water. When yellow light is in focus at the retina the red is tending to a focus behind, while blue light is brought to a focus in front of the retina, and if the eye be adjusted for red light preceding from ∞, blue light must be divergent from about 66 cm. in order to be focussed at the retina at the same time. This shows a refractive difference, or a mean dispersion, for red and blue of about 1·5 D.—in other words, the eye must accommodate 1·5 D. more for red than for blue light; this has been confirmed by experiments. An eye is emmetropic when the retina is at the focus of yellow light so that, approximately, the normal eye is myopic 1 D. for blue and hyperopic ·5 D. for red light; thus there are overlapping blue and red confusion discs at the retina when the yellow is sharply focussed thereon. Therefore when the P. R. is at ∞ for yellow light, it is negative for red and positive for blue, and the P. P. is more distant for red and nearer for blue. Near points with coloured glasses can be easily measured, but loss of light makes measurement of the P. R. more difficult.

The effects of chromatism are not noticeable in ordinary vision because red and blue possess but little luminosity as compared with yellow; further, the confusion discs are spread over a less sensitive part of the retina than that impressed by the yellow, but if the latter be excluded from the eye, the difference between the foci of red and blue is more manifest. This is achieved by using a cobalt blue glass which cuts out the centre of the spectrum and it is because the eye is chromatic that cobalt blue glass serves as a test for ametropia. Even in the latter condition the effects of chromatism are not generally appreciated, although frequently an astigmat notices coloured fringes on the bars of an astigmatic chart.

It is reasonable to presume that the visual acuity would be somewhat better if there were a common focus for light of all wave-lengths. There does not, however, seem to be any measurable improvement if the extreme colours are cut off, which may be done by using a yellow glass. We have no means of comparing the vision of an achromatic with that of a chromatic eye since the former does not exist and cannot be obtained in practice.

The following experiments, among others, prove the chromatism of the eye :—

With very strong illumination a faint purple border can be seen at the edge of a white body and this fringe is the more pronounced if the eye accommodates for a point nearer to or farther than the object.

With a cobalt blue glass a hyperope, looking at a disc of white light, sees a blue centre with a red border, while a myope sees a red centre with a blue border. An emmetrope sees the disc as purple, but if he accommodates for a nearer point he sees a blue border; if for a more distant point, a red border.

If half the pupil be occluded by a card, the eye is converted into a strong prismo-sphere and the coloured fringes, unnoticed in ordinary vision, fall on the macula and are seen, if a small white body on a black ground, or the windows above and below a dividing sash, be viewed. If the lower half of the pupil be occluded, the eye acts as a prism base down, so that a blue-violet fringe is seen at the upper, and a red-orange fringe at the lower edge of a luminous body. In the case of the window sash there would be red above and blue below, if the surrounding panes are the luminous bodies, and the reverse if the sash is luminous and the window dark, as at night. A small near red object appears nearer than if blue because more accommodation is needed to see it clearly.

Chromatism is, of course, quite distinct from colour vision or colour blindness. The former is due to the absence, in the optical system, of compensating variable refractivity for the variable refrangibility of the components of white light. The latter is a function or a defect of the receptive, transmissive or interpretive faculty of the visual apparatus. If the chromatism of the eye be taken as that of water, and provided that the proper glasses could be found, we could make an eye, which is myopic 33 D., achromatic by giving a -33 D. lens made of flint glass whose ν is $27{\cdot}5$, whereas if an eye is emmetropic it could be made achromatic by means of a lens made of crown and flint components so that their united dioptric powers is 0 for yellow light, about $+{\cdot}5$ D. for red and -1 D. for blue light. To produce such a lens the crown would need be about $+66$ D. of $\nu = 55$, and the flint -66 D. of $\nu = 27{\cdot}5$. Although the effects are quite negligible, an ordinary Cx. lens tends to increase and a Cc. tends to decrease the natural chromatism of the eye before which it is placed.

Spherical Aberration.—Spherical aberration exists to a certain extent in the eye, but its effects are in general too slight to be noticeable. Like ordinary simple spherical lenses the aberration is positive, *i.e.* the peripheral portions have a relatively higher power than the centre, but in some cases, especially during accommodation, the aberration may be negative, in which condition the centre has relatively the higher power. Spherical aberration can be proved to exist by finding the far point of the eye for different zones, and for this purpose the optometer of Young is useful. Tscherning, in experimenting with this instrument, discovered that, in a great many instances, the aberration was reversed during accommodation, a fact that seems to confirm his theory of accommodation. Also if the eye be rendered myopic by means of a suitable plano-convex lens, on the plane side of which a fine cross-line screen or grid is etched, the shadows of the grid cast on the retina will be seen, not as a chess-board pattern, but with a certain amount of barrel or pincushion distortion towards the periphery. It was by means of a grid of this description that Tscherning studied the ocular spherical aberration and with which he was able to prove that, in the majority of cases, spherical aberration became negative in strong accommodation. In retinoscopy with dilated pupils, the reflex is generally broken and confused by the spherical aberration existing in the extreme exposed portions of the cornea and crystalline.

Spherical aberration is naturally corrected to a great extent by the peculiar formation of the crystalline, whose index and power increase towards the nucleus, and by the action of the iris in cutting off the more marginal rays. The pupil also becomes smaller during accommodation, and may therefore compensate for any aberration introduced by increased obliquity and divergence of the incident light. In ordinary circumstances, however, the retinal confusion is very slight and cannot affect the visual acuity to any marked extent.

Coma is spherical aberration for oblique pencils of light, in which the circle of confusion is not formed symmetrically with respect to the theoretical focus, but is lopsided and resembles a comet, the tail of which is turned radially away from the optic axis.

Now the visual line of the eye is really a secondary axis and therefore the focus produced by a pencil, of which it is the axis, must in general suffer from coma. Thus since the macula, with respect to the posterior pole, is situated downwards and outwards on the retina, the image of a point formed on the macula may exhibit a slight blur in a downward and outward direction, *i.e.* away from the optic axis, and would be projected in the visual field as upward and inward. Should coma exist to any appreciable extent it can be enhanced by slightly accommodating or by rendering the eye myopic with a convex lens. The asymmetrical blur is by this means rendered more noticeable, and is very often detected by ametropes in testing for stigmatism, but it does not, of course, follow that the direction of the coma is the same in all eyes since the obliquity of the crystalline and cornea may introduce a variation. For example, suppose an ordinary sunrise astigmatic chart be employed, the lines of which are arranged in pairs; a person having coma, and whose vision is slightly blurred, will sometimes say that, in a particular direction, one only of each pair of lines is clear, or the one is light grey compared with the other. This is due, of course, to the coma from the white space on one side spreading sideways over the image of the adjacent bar, thereby reducing its blackness. The average person's visual axis passes out of the cornea on the upper and inner side, and therefore the projected image of the tail of the coma is also turned in that direction; such an eye would see unequally those pairs of lines in the neighbourhood of 45°, *i.e.* those at right angles to the tail, although there may be no astigmatism. Of course the effect may lie in other directions depending upon the exact optical condition of the eye as a whole, but in the majority of cases the coma extends upwards and inwards in the visual field, or downwards and outwards on the retina in a direction away from the optic axis. Again if a small white spot on a dark background be viewed, and accommodation exerted sufficiently to throw the image slightly out of focus, the circle of confusion will be seen to spread more on one side than the other.

Radial Astigmatism is, of course, present to a certain extent in the eye but its effect at the macula is practically nil. In the more peripheral portions of the image astigmatic foci doubtless exist, but the retina is too insensitive to appreciate them. In addition it has been calculated that the curvature of the retina practically coincides with the surface passing through all the circles of least confusion so that, even if the periphery of the retina were sufficiently sensitive, it would not detect a great deal of astigmatism except during accommodation, when the surface of least confusion undergoes some alteration in radius.

Curvature of the Field, for the same reason, is rendered innocuous, the contour of the retina affording a natural counteraction.

Distortion likewise can be said to be practically negligible, although it may exist to a very high degree for oblique pencils. Here, however, we have the factor of education coming to our aid because, although the peripheral image of a straight line may be curved, yet the mind interprets the object as a straight line simply from experience and habit. In addition, of course, we have the ever-present factors of retinal curvature and diminished retinal sensitivity away from the macula. It should be observed, however, that in this sense distortion is distinct from that mentioned under *Spherical Aberration.*

Aberration of Lenses.—Chromatic aberration caused by ordinary single lenses is rarely noticed, except sometimes during a test, but even then the chromatism is rather of the eye than the lens. Aberrations of form are noticed only with strong lenses and prisms; when first used complaints are often heard that straight lines look oblique or objects appear too large or too small, too near or too distant, that the floor looks concaved or convexed. With Cx. lenses and prisms base in, objects appear larger, nearer and convexed, and *vice versa* with Cc. lenses and prisms base out. To a certain extent some of these effects are mental and if the lenses are of correct power they soon disappear, as do also the distortion and obliquity of straight lines caused by oblique cylindricals.

Accommodation and Pupillary Contraction.—Why the sphincter iridis should contract in near vision, more than sufficiently to overcome dilatation caused by the crystalline advancement, is not clear. It is true that more light enters the eye from the same object when near than when it is distant, but this is counteracted to a great extent by the altered size of the retinal image. Also, while spherical aberration might be increased owing to the greater dioptric power of the accommodated eye, it is doubtful if this is really so, because the form of the eye is rather better adapted for divergent light, and Tscherning shows that the aberration is negative when the object viewed is near the P. P. Assuming this to be the case we may draw the deduction that the point of no spherical aberration is somewhere near the reading distance, as judged by the apparent movement of an object viewed through a pinhole disc.

Pinhole Experiments.—Owing to the non-coincidence of the retina and the principal focus, an object at ∞ viewed through a pinhole appears to move "against" in H. and "with" in M. when the disc is moved laterally. In Em., movement of the object is imperceptible or is very slightly "with" owing to spherical aberration, but some emmetropes see "with" movement at ∞ and against at the P. P., it being neither with nor against at some intermediate distance, say, 1 m. The apparent movements are, however, so variable and uncertain that little reliance can be placed on them.

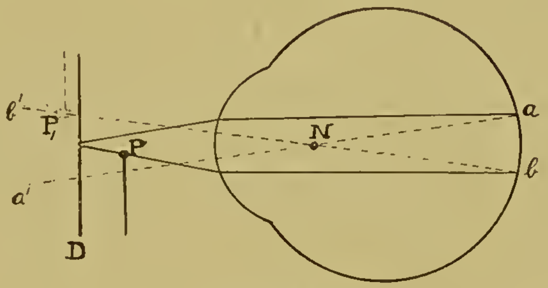


Fig. 76.

The pinhole can be employed to prove the law of projection, and that upright vision is a result of inversion of the real retinal image. Let D be the pinhole held close to the eye at about F_1; then the light passing through the aperture is approximately parallel on reaching the retina and forms thereon a disc of illumination ab about the size of the pupil. The projected image of ab is represented by $b'a'$ and if a pin P be placed between D and the eye, as in Fig. 76, an upright shadow will be cast on the retina. This shadow is projected as P_1, an inverted image of the pin, and is seen on the opposite side to the actual position of the latter.

Visual Phenomena, etc.

Continued Retinal Impression.—The retinal stimulus caused by the impingement of light lasts for a certain time before the effect passes away, and the sensation of vision has been divided into (*a*) an initial period, (*b*) a period of increase to the maximum, (*c*) a period of persistence of sensation with gradual decline, (*d*) a period of rapid fall and obliteration of the sensation. These periods combine to form a single impression which is of definite duration. For example if a small luminous body moves with great rapidity the stimuli at every point of the retina, on which its image is formed, follow each other with such celerity that the impressions previously excited have not had time to cease before the succeeding ones are caused, and the consequence is the mental impression of a streak of light. This is illustrated by a falling star, by lightning, or by the sensation of continuous motion as seen projected by the bioscope. Further, the experiments of rotating colour discs, mentioned in Chapter XIV., are another illustration of the persistence of visual sensations, the effect in this case being to produce the sensation of white by the admixture of all the spectrum colours on the retina.

Visual Fatigue.—Visual fatigue results if a retinal impression be long continued. In ordinary circumstances visual fatigue is not noticed; the retina is refreshed by the gaze being constantly turned from one object to another, so that a new impression is made on that part of the retina previously occupied by some other image. Also some degree of rest is obtained for the retina by frequent blinking; the pupil being covered by the lid, the light is thus excluded for the moment. The eyes should never be engaged in viewing bright objects for more than a certain time, say half an hour or so without rest, but a more permanent form of relief is obtained from the use of smoked or spectrum blue glasses. Neglect of these precautions render the eyes very irritable and therefore more liable to other troubles.

During sleep the retinal function is for some hours entirely inactive, and it is probably then that the visual nervous energy is stored up. Sleep is thus the preserver and restorer of the retinal function, a fact that is shown by the weakened condition of the sight of those who, for some reason, have been deprived of their usual quantity of repose. The lids not being quite opaque, sleep is more refreshing when the room is in total darkness; the brighter the light, the less true rest do the eyes obtain.

When a person passes from a bright into a dull light, nothing is clearly distinguished for a short time, and the inability to see in such circumstances may be so great as to cause a momentary blindness. This is partly due to exhaustion of nervous energy by excessive previous stimulus and partly to other causes connected with the visual purple. An opposite condition is brought about when one passes from darkness to, say, sunlight, in which circumstances vision is, at first, impossible and positively painful.

Demonstration of Retinal Fatigue.—Retinal fatigue can be demonstrated by the following simple experiments: Cover half a sheet of white paper with black velvet and look steadily at both so that one part of the retina is strongly stimulated while the other is at rest. As soon as the eye begins to get tired, remove the velvet, and the part of the paper previously covered will appear very vivid and bright, while the part which was previously uncovered will be dull or grey by contrast. Another experiment, which shows how the functional activity of the retina is temporarily diminished by continued use, is to put in front of one eye a dark smoked glass for some minutes, when, on its removal, the difference in the intensity of the impressions received by that and by the other eye is quite marked.

After-Images.—The altered action of the retina under fatigue, due to over-stimulation, produces *after-images.* In the experiment with velvet previously mentioned, the dark grey is the after-image of the original bright white, and the latter is the after-image of the original black. If a person looks at a white spot on a black background, until the eyes are fatigued, and then turns his eyes to a sheet of grey paper, he will very shortly see a dark spot on a white background, this being the after-image of the original white spot on a black background.

Saturation of the retina by a certain colour produces an after-image of its complement. Thus if a red spot is looked at the after-image is blue-green; if the spot is blue-green, the after-image is red provided the gaze be turned to a fairly bright white or grey surface. The colours thus seen are very vivid and pure, and convey the idea of complementary colours far better than any illustration with pigments. After-images consisting of colours complementary to the original are negative and due to retinal exhaustion. Such an after-image is not, however, always of the complementary colour, as it varies with the background.

If one looks fixedly at a bright light, such as the filament of a glow-lamp, and then the eyes be shut, an after-image which is the same colour as the original, but of diminished brightness, will be seen. This is a positive after-image caused by the continuation of the original retinal stimulation, and it changes later on to a negative after-image which passes through many of the spectrum colours before it disappears. A bright electric light, if unshaded, causes so strong a positive after-image that temporary inability to use the eyes results in consequence of fixedly gazing at it. Looking at the sun with the naked eye, or through an unprotected telescope, is very dangerous to vision since it may produce an after-image which may last for a considerable time, or even cause a permanent partial scotoma at the macula. In this latter case there is an actual structural change in the retina analogous to a burn.

Recurrent Vision.—If in a dark room an instantaneous flash of light, such as a spark from a coil, be seen, the original image, after dying away, is quickly replaced by a second positive image and sometimes by two or three others. The first recurrent image is often very bright and takes about 1/4 of a second to form, but those following are progressively fainter. Similar phenomena can be produced if the eyes be covered by the hand for a minute or so and then uncovered, for the briefest possible time, to see a bright object such as an electric lamp or window, but best of all is to use an ordinary camera shutter, such as the roller blind, working at moderate speed. When this is held before the eye and released to expose a bright landscape the recurrent image is very distinct. Recurrent images are momentary positive after-images whose colours correspond to those of the object, and are followed later by the more persistent negative after-images which are of different and varying colours.

Entopic Phenomena.—Certain structures in the lens, vitreous or retina, can be rendered visible to the eye itself, and such vision is known as an *entoptic phenomenon.* Thus, opacities and normal striæ in the crystalline lens, and those due to cataract, can be seen by looking at a white cloud through a pinhole disc, for when the latter is at the anterior focus of the eye, the light in the vitreous is in the form of a parallel beam whose diameter is that of the pupil, and any obstruction in the eye causes a shadow to be situated on the retina. In the same way semi-transparent cells and bodies floating in the vitreous can be seen. An opaque obstruction causes a complete shadow and if transparent or nearly so, but of different refractive index to the surrounding parts, the light traversing it is more or less refracted, thus giving rise to a luminous area with a dark border, or a dark area with a luminous border.

Muscæ Volitantes consist of semi-transparent colourless cells, often joined together like a row of pearls, or of irregular ill-defined threads, which float about in the vitreous. These cast shadows on the retina which may be noticed on looking directly at a white cloud, but better through a pinhole and still better on looking at a brilliantly illuminated white surface such as the blank field of a microscope; they generally tend to fall slowly to the bottom of the field and then rise suddenly to the top. Sometimes these muscæ are projected as black specks, or threads, which are fixed in position, and are then often very annoying; myopes are especially liable to be affected by them. Unless very numerous, however, they need not give rise to anxiety, and they cease to be noticed if attention is diverted from them and the health braced up. The movements of these specks, etc., naturally coincide with those of the eye itself; hence the name given to the phenomenon.

Corpuscula are colourless nearly transparent specks which, if one looks steadily at the sky through a pinhole, can be seen flitting about with great rapidity and traversing every part of the field excepting the macular area. Sometimes they can be seen to follow the same tract, which may be in a curve, and it is probable that they are caused by the white blood corpuscles being carried through the capillaries in the middle zone of the retina, thus giving rise to shadow images. They generally appear elongated and not spherical on account of their rapid motion.

Other Entoptic Phenomena.—On winking or rubbing the eye disturbance of the cornea and lachrymal moisture causes striæ or specks to be seen. If the pinhole be slowly moved to and fro a finely granulated, striated ground may be noticed, while if it be moved rapidly with a circular or lateral motion, the field will be seen filled with a dark network of lines somewhat resembling the branches of a tree, in the centre of which a dark spot will be seen from which the lines are absent. A similar but much more striking effect is produced when, in a dark room, a lighted candle is waved about close to, and just below, the line of vision. This phenomenon is due to the projected shadow images (Purkinje's) of the retinal vessels on to the receptive layer behind them, and is a picture of the observer's retinal bloodvessels on an apparently dark brown background. As a rule both the macula and the fovea can be seen surrounded by fine capillary loops, none of which are visible inside the macular area. With care and under favourable circumstances the retinal field may be traced to a considerable distance towards the periphery. Another experiment, giving more or less the same result, is to turn the eye inwards and then concentrate, by means of a condenser, the light of a lamp on to the sclerotic as far back as possible. In this case the centre of the projected field appears dark blue and concentric waves flow inwards from all sides towards the centre. This flowing into the macula from surrounding parts also occurs when gazing fixedly at a spot in the sky. Various more or less uniform luminous entoptic phenomena can be caused by the pressure of the lids on the eye, by movements of the eyes, by accommodation, or indeed by anything which causes slight stimulation of the retina either by mechanical or increased blood-pressure. If the eye be closed, turned inwards as much as possible, and gently pressed by a pencil at a point near the outer canthus, a luminous impression, called a *phosphene*, is produced and projected to the opposite side of the eye. Finally, if the latter be closed or open in an absolutely dark room, the field appears to be filled with a dark grey mottling doubtless due to blood-pressure and circulation in the retina, although by some it is ascribed to phosphorescence.

The Macula Lutea, or yellow spot, is so termed because after death it is found to be that colour, but whether it is actually yellow during life seems to be undecided.

Now when a photograph is taken on a plate sensitive to the whole of the visible spectrum, a yellow filter, made of glass or of dyed gelatine, is placed in the path of the rays to restrain the intense actinic action of the blue-violet end of the spectrum, in order that the red, orange and green rays may have time to exert their action on the sensitized film. According to Lindsay

Johnson, the eye possesses a similar yellow filter consisting of an exceedingly fine plexus of capillary vessels which lies in the inner layers of the retina, and therefore in front of the rods and cones, but at the yellow spot (fovea) these capillaries are absent and, therefore, nature has placed there a yellow pigment immediately behind the rods and cones. Since light passes through the retina to the choroid and is reflected back to the cone terminals, it traverses this pigment layer twice, so that its effect is doubled. Were there no yellow pigment at this spot one would probably see a blue-violet disc in the line of sight, when looking at the sky or other bright whitish surfaces, owing to the free passage of the blue-violet, which is partially cut out by the above-mentioned plexus over the remainder of the retina.

The Visual Purple is a colouring matter first discovered by Boll, of Vienna, in the eyes of frogs. It exists in the eyes of man and many animals and plays an important part in vision, even if it be not really essential for sight. By some it is thought to be the means of converting the energy of incident light into a form which the bacillary layer of the retina and the optic nerve can communicate to the brain, and it would thus be essential to vision. Under the action of light not only is the visual purple bleached in direct proportion to intensity of the former, but the hexagonal cells send out processes which pass down between the rods, carrying with them the purple-brown secretion. In darkness the processes withdraw and leave the rods free, while at the same time the visual purple accumulates. The latter surrounds the rods to a greater depth than the cones, and none is found at the fovea, where the cones most abound and the rods are absent. Further, we know that the fovea is less sensitive to very dim light than the immediately surrounding portions of the retina, and this would be explained on the theory that the purple is not essential to vision, but that its function is rather to enable one to see better in a dim light, for if one goes from brilliant sunlight into a dimly lighted room, it takes some little time before one can see anything, but gradually objects become more and more clear. The probable explanation of this is that in bright sunlight the visual purple is used up as fast as it is formed, so that if one goes into a dark room the visual purple, which is quite sufficient to enable one to see in bright sunshine, is altogether inadequate to see in a dim light.

The back of the eye in most animals has a brilliant yellow, green, orange, or purple colouring matter, called the *tapetum*, but whatever the colour may be it fades under the action of light, and if a piece of the human retina be removed from an eye in the dark and spread out on a glass slip, it appears a reddish yellow-violet (chamois) colour when brought into the light. In a few minutes the colour fades away, but when the rod and cone side of the bleached retina be laid on a piece of the choroid carrying the hexagonal ayer of the retina (which must be quite fresh), the colour will return again, thus showing that it is secreted by this layer. If a piece of retina be laid on a glass slip, and covered over with a small design cut out of black paper, or a small negative, and then taken into the light, all the parts exposed to the light become bleached, while the part covered by the negative or paper remains reddish-purple. This will likewise fade away unless fixed in a 4 per cent. solution of alum in the dark; thus a natural print, called an *optogram*, may be obtained.

Haidinger's Tufts.—On looking at a bright sky through a Nicol prism or plate of tourmaline, one will sometimes see a pair of small yellow cones joined end to end like an hour-glass, which are known as Haidinger's tufts or brushes; at right angles there is a pale blue or violet colour. Sometimes the yellow tufts are seen and sometimes the blue, and by some the appearance is described as a cross having one arm yellow and the other blue. The major axis of the tufts turns when the polarizer is rotated, and after a few seconds the tufts vanish, but immediately reappear on smartly rotating the plate. If a deep cobalt blue glass be held before the prism, the tufts appear smaller and of a dark reddish tint, due to the absorption of the yellow rays by the blue glass.

Fig. 77.—Haidinger's Tufts.

(From the original photograph by Professor W. F. Barrett, F.R.S.)

Prof. W. F. Barrett has shown that if a screen, which cuts off all orange and yellow rays, be held before the eye while looking at a bright white surface, a dark reddish patch is seen in the blue field because the macula lutea, being yellow, is then more or less opaque to blue-green light. If now the Nicol prism is placed in front of the glass, the tufts are seen in the position of the dark patch, showing that they are, in some way, connected with the macula. The colour of the tufts is probably due to that of the yellow spot, the blue filling of the concavities being the result of complementary contrast, but some uncertainty exists on this point since many people describe the tufts as blue or purple without any yellow at all. Haidinger's brushes are held to prove that the light of direct vision is polarized, and that the eye is capable of analyzing polarized light. The tufts are longest when the plane of polarization is horizontal, thus showing that the macula has a longer horizontal than vertical diameter. The cause of this phenomenon is not due to the crystalline since it may be seen by an eye from which the lens has been removed.

Scotomata.—A scotoma may be defined as a gap in the field of vision, and is *positive* if seen and *negative* if not seen.

A positive scotoma may be caused by an opacity in either the lens or vitreous casting on the retina a shadow, which is projected out as a dark patch in the visual field. A small hæmorrhage lying between the retina and the vitreous may produce a scotoma, and this is generally red at first owing to the other colours being absorbed. A deposit of pigment is also a common source and gives rise to a black scotoma, which is readily perceived when one looks at a white sheet of paper. Muscæ volitantes are faint positive scotomata.

A negative scotoma may be physiological, *e.g.* that caused by the blind spot; faint negative scotomata are also due to the large retinal vessels which are not quite transparent. Negative scotomata also occur in disease, especially in the macular area, as in tobacco amblyopia, and are only perceived when white or coloured objects are looked at. Towards the periphery of the field all colours normally disappear in turn, green first, then red, yellow and lastly blue, so that everyone has physiological negative peripheral scotomata for colours. (Vide *The Field of Vision.*)

FIG. 78.—THE BLIND-SPOT TEST.

The Blind Spot.—The projection of the blind spot is not noticed in the field of view for the simple reason that the optic disc is altogether insensitive to stimulation and cannot, therefore, appreciate either the presence or absence of light. The mind unconsciously fills in the gap or, as it may be termed, the physiological scotoma caused by the blind spot, with colour or whatever else happens to occupy the surrounding portions of the retina. Thus if one looks at the sky with one eye, there is no appreciable break in the field of vision, and it is only in special circumstances, as in Mariotte's experiment, that the presence of the blind spot can be demonstrated. Even were the gaps appreciated as scotomata they would hardly be noticed in binocular vision, for then the two fields overlap, so that the right eye would see the portion left blank by the projection of the left disc and *vice versa.*

Mariotte's Experiment.—Let the left eye be closed and the right directed towards the cross (Fig. 78) held in the axis of vision. If now the page be slowly withdrawn or approached towards the eye, a position will be found at which the round spot becomes invisible; on withdrawing or approaching the page from this position it again comes into view, and by looking to the right or left of, or above or below, the cross the same result can be obtained. In this way the area of the blind spot can be mapped out on paper and its exact size calculated; such measurements show it to be about 2·25 mm. in the horizontal and a little more in the vertical.

Plotting the Disc and Macula.—It is instructive and interesting to actually locate, by projection, the position of one's own disc relative to the macula and posterior pole.

To do this place the eye, say the left, a certain fixed distance, *e.g.* 10″, above a sheet of paper, the other eye being closed or occluded. On the paper mark a dot M, and through M draw a horizontal straight line (Fig. 79); now take a pencil and, carefully fixing its point, cause the eye to travel slowly inwards away from M by moving the pencil to the right along the line. At a certain point A, M will disappear, showing that its image has reached the nasal side of the disc, where the sensitivity is nil. Continue the movement of the pencil until the dot M reappears, when the pencil has reached the spot B. AB is then the lateral (projected) diameter of the disc, on a horizontal drawn through the macula. In the same way, by moving the pencil upwards and downwards on a line bisecting AB, the upper and lower extremities C and D of the disc will be located, and a rough ellipse described through the four points will represent the approximate shape of the blind spot.

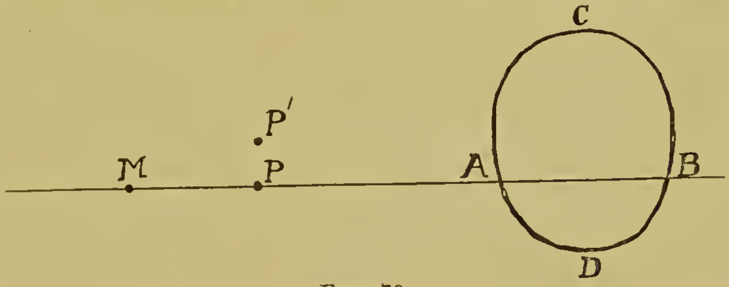


FIG. 79.

From actual measurement it is easy to calculate the distances between the macula, posterior pole P, and the disc for any given eye. For example, we know that the distance MP between macula and pole represents 1·25 mm. if we assume that MP subtends an angle of 5° at the nodal point, *i.e.* that angle alpha is 5°. Further, by measuring PA, it is a matter of simple proportion to find the length in the eye to which PA corresponds. Thus supposing the experiment were made at 10″ or 250 mm. we have—

$$d : PA :: 15 : 250$$

where d is the actual distance from pole to disc required, and 15 the distance in mm. of the nodal point to retina, whence—

$$d = \frac{PA \times 15}{250}$$

If PA be 40 mm., d is then 2·5 mm., which is about the value found in practice. It will be noticed that the horizontal line passing through M

cuts the disc near the lower edge, proving that the macula is below the centre of the disc; thus the maximum width of the latter is not represented by AB. Assuming the disc to be level with the posterior pole, the true position of P would be in the neighbourhood of P', although for practical purposes we assume that the macula, posterior pole and centre of disc, are all on the same horizontal line. The method of sketching indicated is easy and convenient, in that it gives an *upright* representation instead of an inverted one; the latter is obtained by fixing the point M and moving the pencil about to locate, as in the perimeter, the confines of the disc. This, however, is not so accurate unless a small object, such as the head of a large pin, be substituted for the pencil.

Some Peculiarities of Ametropic Vision.—Myopes of high degree may see a star, or point of light, as a rosette, there being multiple images clustering around a centre, the outer ones merging into the central image when the M. is corrected. Also a myope, who has good vision when corrected, may see or count the fine white lines on an astigmatic dial without any lenses, although with V. below 6/60. The images of these lines formed in the vitreous are parallel to those of the chart, and from them the light diverges to form, on the retina, bands which overlap each other. This overlapping produces thin lines of greatest concentration of light, which are apparently the images of the actual lines, but they do not correspond in number to those of the chart.

An eye out of focus often sees Snellen's type doubled, the second images resembling a shadow of the other. This is more frequent and marked where there is a low degree of astigmatism, and it seems to be most common when one focal line is at, or near, the retina and the other in front. As mentioned in Chapter VII., an astigmat, when nearly corrected, often sees the lines on a chart bordered with various colours.

A person having principal meridians, say, vertical and horizontal, sometimes states that with his correcting lenses the vertical and horizontal bars of an astigmatic chart are perfectly and equally clear, but that intermediate ones at 45° and 135° are less clearly defined and greyish in appearance. The explanation of this peculiarity is difficult to find but probably lies in the shape of the minute confusion discs at the retina. In addition the effects of coma, etc., may enhance the appearance but cases of this type are rare and may be attributed to personal peculiarities on the part of the subject.

Effects of Variations in the Refractive Indices of the Eye.—Increase of the refractive index of the cornea, cortex of the lens or of the vitreous, would cause the eye to have *less* refractive power or would increase the focal length, and so cause refractive hypermetropia; whereas any increase in the index of the aqueous, or of the nucleus of the lens, would augment the refractive power or shorten the focal length, and so cause refractive myopia. A decrease in the various refractive indices above mentioned would cause the opposite conditions. Advancement of the crystalline causes increase of refractivity and its retirement towards the retina has a contrary effect.

Notes on Changed Conditions of the Eye.—If the crystalline lens were in air its focal length would be about 8 mm. Were the aqueous absent, and the two surfaces of the cornea were presumed to neutralize each other—*i.e.* if light were incident from air to the front of the crystalline, the posterior focal length of the eye would be about 24 mm., and the anterior about 18 mm. Thus, removal of the cornea and aqueous would not materially affect the *refractive power* of the dioptric system, but the principal and nodal points would lie much nearer to the retina, and the eye would be consequently highly hypermetropic. In this case the first medium, from which the light comes, has $\mu = 1$, and the refraction is produced at the anterior surface of the crystalline and anterior surface of the vitreous.

The Eye in Water.—If the eye be immersed in water, the effect of the cornea and aqueous is lost, and the eye is highly hypermetropic to the extent of about 22 D. In this case the first medium has $\mu = 1{\cdot}33$, and since the μ of the cornea and aqueous is practically the same as that of water, the refracting power of the former vanishes and we have the crystalline only as the refracting body. Taking F of the Crys. as 60 mm. and treating it as a lens whose optical centre lies 18 mm. in advance of the retina, we obtain the far point of the eye from—

$$\mathrm{R} = \frac{60 \times 18}{18 - 60} = -25 \text{ mm. (approx.)}$$

or the eye is H. 40 D. If the correcting lens be placed 20 mm. in advance of the refracting plane or optical centre of the crystalline, its focal length would be $25 + 20 = 45$ mm., corresponding to a power of 22 D. The lens would preferably be a bi-Cc. air lens, which has the same effect as two water surfaces convex to each other. Its radius of curvature is obtained from—

$$45 = \frac{1{\cdot}33r}{2(1 - 1{\cdot}33)}$$

whence $r = -22{\cdot}5$ mm.

If the water be salt and therefore of slightly higher μ, the focal length of the lens is shortened or its dioptric power increased. On the other hand, the power of the eye is decreased, since the cornea would act as a negative lens if the medium in contact with it be of higher μ. Consequently the same lens would serve for either fresh or salt water if placed at a suitable distance in front of the eye. If, however, a diver uses a helmet having flat glasses, he sees the same as if he were in air and looking into a tank of water.

If an eye is in water and looks out into air, the whole field of 180° is crowded into an irregular space equal to twice the critical angle of water, or about 97°. In addition those portions of the field seen almost normally to the surface appear more distant by an amount equal to about $t/3$, where t is the real height of the object above the water.

CHAPTER XVI

OPTOMETRY AND LENS ACTION.

Influence of the Position of the Lenses.—When the point of vision is at ∞, the effective value of a Cx. lens increases as the latter is farther out from the eye, while that of a Cc. lens decreases, so that when we speak of so many diopters of H. or M. as represented by the correcting lens, there is actually more H. and less M. respectively. For the correcting lens to be numerically equal to the refractive error, it would need be placed in the principal plane of the eye. This being impossible, the best position is that which is also the most convenient, viz., as near to the tips of the lashes as possible, which position does not often differ much from the anterior focal plane; let this be regarded as the normal position. In this position, which is about 15 mm. from the cornea, the lens does not alter the size of the image from that formed by the *static* refractive power of the eye alone and, therefore, it is commonly said that the retinal image is then the same size as in Em. The refracting power of an Am. eye is taken as being the same as that of an Em. eye, but in the former the retina is too near or too far away, while in Em. it is in the posterior focal plane. The correcting lens in Am. shifts the image to the retina, but it would also cause it to be larger or smaller unless situated in the anterior focal plane F_1. A Cx. lens nearer, or a Cc. farther, than F_1 decreases the size of the retinal image; a Cx. farther or a Cc. nearer than F_1 increases it. These effects are fully discussed in Chapter XX.

If a certain lens moved out from the eye does not impair V., we can conclude that equally good sight would obtain with a stronger Cx. or a weaker Cc., but the value of the indication is discounted somewhat by the respective increase and decrease in the size of the retinal images. Again if a certain lens in the normal position corrects an error, we could also correct it with a weaker Cx., or a stronger Cc. placed farther out. Vision through a medium power Cx., held a few inches away, is impossible, although there is magnification, but if the lens be brought close to the eye objects may be seen through it much more distinctly. It is impossible to see clearly through a strong Cc. placed close to the eye, but objects become quite distinct, although small, when the lens is moved outwards a sufficient distance.

Thus for *parallel light* the effectivity of a Cx. lens is always increased, and that of a Cc. decreased, as the lens is farther out from the eye and such changes are proportional to the power of the lens and the departure from the normal position.

When light is *divergent* the changes are different. With a Cx. lens the effectivity for a near object increases as the lens is carried outwards but not to so great an extent as when the object is distant, and the *lessened increase* of effect is *greater* as the point of view is nearer, the *minimum increase* being reached when the object viewed is in front of the lens at a distance equal to twice its focal distance. If the distance of the object beyond the lens is less than 2 F., a further approach of the lens towards the object and away from the eye results in a diminishing effectivity. The latter then becomes less and less as the lens approaches the object and is zero when the two are in contact, *i.e.* if the Cx. be placed in contact with print, the effect is the same as if the lens were not there.

Thus a person using Cx. lenses, adapted for distance, can produce artificial Ac. for near objects by moving the lenses out from the eyes, provided such objects are distant more than 2 F. from the lenses. Also if a hyperope, or presbyope, is under-corrected he can increase the lens effectivity, for reading purposes, by placing the frame farther down the nose, provided the lenses are stronger than + 5 D. if he reads at 40 cm., or stronger than + 6 D. if he reads at 33 cm. If the lenses are weaker than those mentioned, he can only increase their effectivity by pushing them closer to the eyes, or by leaving them in position and moving the head back. If a person wearing, say, + 2 D. or + 3 D. places the frame farther down on the nose, as is sometimes done when reading is unsatisfactory with them in the normal position, he produces a slightly more blurred but larger retinal image and, from the latter, he may be enabled to read print which otherwise he could not.

With a Cc. lens a decreased effectivity always results from increased distance between the lens and the eye, no matter how near the object viewed may be. But, for a given separation, the *decrease* of effect is *lessened* as the object is nearer, and the minimum is reached when the lens touches the object, it being then zero the same as with a Cx. lens. A person, using Cc. lenses too weak, will push them as close as possible to the eyes in order to increase their effect, and the size of the retinal images, and consequently improve his vision for distant objects. In order to produce artificial Ac. he will move the lenses outwards, and may thus be able to see clearly objects which are situated nearer than ∞. When the accommodative action is weak he will place the frame farther down the nose, in order to be able to read more easily, if indeed he does not prefer to remove the glasses entirely.

Summary of Effects.—The effectivity of a lens *moved outwards* from the eye can be summarized for distances *between the object and the lens* from ∞ to zero thus :—

	With a + Lens.	With a − Lens.
Object at ∞..	Increased effect	Decreased effect
Object between ∞ and 2 F.	Lessened increased effect	Lessened decreased effect
Object within 2 F.	Decreased effect	Lessened decreased effect
Object touching lens ..	No effect	No effect

The reader must distinguish between the *changes* of effectivity referred to in the foregoing articles and the actual effectivity of a lens on the eye.

Increased *positive* effect, *i.e.* artificial Ac. results from increasing the distance *between the eye and the lens*, whether the latter be Cx. or Cc., but with the former there is an increase and with the latter a decrease in the size of the retinal image. For calculation see *Artificial Accommodation.*

Effectivity of a Lens.—Let D be the power of the lens, d its distance in cm. from the principal plane of the eye, and D_E the effective value. Then we have—

$$D_E = \frac{100\ D}{100 - d\ D} = \frac{D}{1 - \cdot 01\ d\ D}$$

Thus if the lens be + 5 D. placed 1·65 cm. from the refracting plane—

$$D_E = \frac{5}{1 - (\cdot 01 \times 1\cdot 65 \times 5)} = 5\cdot 45$$

If the lens is − 5 D.

$$D_E = \frac{-5}{1 - [\cdot 01 \times 1\cdot 65 \times (-5)]} = -4\cdot 62$$

i.e. a + 5 D. placed 1·65 cm. from the refracting plane corrects 5·45 D. H., while a − 5 D. similarly placed corrects 4·62 D. M.

If the true refractive error, which is equal to D_E, be known and represented by the lens correcting it, placed in the principal plane, we can find D. the correcting lens, placed at a distance d, from—

$$D = \frac{100\ D_E}{100 + d\ D_E} = \frac{D_E}{1 + \cdot 01\ d\ D}$$

Thus if there be a true H. of 5·45 D., corrected by a lens placed 1·65 cm. from the principal plane, the power of the lens must be—

$$D = \frac{5\cdot 45}{1 + \cdot 01 \times 1\cdot 65 \times 5\cdot 45} = +5$$

If the true error be 4·6 M.

$$D = \frac{-4·62}{1 + ·01 \times 1·65 \times (-4·62)} = -5$$

The effectivity D_B for a near object, at a dioptric distance B, is as follows:—

$$D_B = \frac{D - B}{1 - ·01\, d\, (D - B)}$$

Suppose the subject to be at 33 cm. in front of a +5 D., and a −5 D., respectively; then—

$$D_B = \frac{5 - 3}{1 - ·01 \times 1·65 \times 2} = +2·07 \text{ and } \frac{-5 - 3}{1 - ·01 \times 1·65 \times (-8)} = -7$$

The amount of accommodation A that a person would need to use, in order to see a near object, if he has been corrected for distance by a lens D placed at F_1 of the eye, is—

$$A = D_E - D_B$$

Taking the two examples given of +5 D. and −5 D. for an object at 33 cm. we have, respectively:—

$$A = +5·45 - (+2·07) = 3·38 \text{ D.}$$
$$\text{and } A = -4·62 - (\ -7\ ) = 2·38 \text{ D.}$$

Thus the Ac. exerted in H. is greater, and in M. less, than what would appear from the ordinary calculations. When a hyperope, or myope, is corrected for distance, we usually say that for reading at 33 cm. he would need to accommodate 3 D., but here we see that in H. 5 D. it is 3·38 D. and in M. 5 D. it is 2·38 D. If a lens were used, however, it would be +3 D. added to the original lens in all cases, so that if +10 D. suits for distance in a case of aphakia, +13 D. is needed for reading at 33 cm. from the lens.

What occurs in these cases can be illustrated by the examples given. In the case of H. 5 D., when the light diverges from 33 it is, after refraction by the lens, convergent to 5 − 3 = 2 D. or 50 cm., and at the eye has a convergence of 100/(50 − 1·65) = 2·07 D.; now since the eye is H. 5·45 D. there is required Ac. = 5·45 − 2·07 = 3·38 D. in order that the light be brought to a focus at the retina. In the case of the M. 5 D., the light after passing through the lens, diverges 5 + 3 = 8 D., or from 12·5 cm. and at the eye the divergence is 100/(12·5 + 1·65) = 7 D., and since the eye is M. 4·62 D., the Ac. needed to focus the light at the retina is −4·62 + 7 = 2·38 D. In these considerations it is presumed that the principal plane has not changed as the eye accommodates.

From this it would appear as if cases of H. need stronger lenses for near work, and cases of M. full distance correction, or practically the contrary of what has been stated when treating of the correction of these errors. With low power lenses, the change due to effectivity is quite negligible.

When the object is at ∞ the dioptric distance B is zero, and D_B is the same as D_E. When d is zero so that the lens, in theory, is in the refracting plane of the eye $D_E = D$, and $D_B = D - B$, which is our ordinary calculation for conjugate foci.

When with a Cx. lens $B = D$, *i.e.* the object is at F of the lens, $D_B = 0$, but in the case of a Cc. this, of course, does not apply; thus with -5 D., in the usual position, and the object 20 cm. distant, the divergence of the light at the lens is 10 D. and at the refracting plane of the eye it is 8·5 D. (approx.).

The value of d, *i.e.* the interval between the eye and the lens, in order to see an object at a certain distance, would be found by transposing the given formulæ, thus—

$$d = \frac{D_E - D}{\cdot 01\ D_E D} \quad \text{or} \quad d = \frac{D_B - (D - B)}{\cdot 01\ D_B\ (D - B)}$$

Or it can be obtained by the method given in *artificial accommodation.* In these calculations, we take the distance of the object as from the lens, for if we were to consider the distance of the object as from the eye, while the lens is in advance of the latter, the calculations become still more complicated.

Simplified Formulæ.—If the position of the correcting lens is taken as being always at 1·65 cm. from the refracting plane, its effectivity is—

$$D_E = \frac{D}{1 - \cdot 0165\ D} \quad \text{and} \quad D_B = \frac{D - B}{1 - \cdot 0165\ (D - B)}$$

$$D = \frac{D_E}{1 + \cdot 0165\ D_E}$$

Effectivity of Cylindrical Lenses.—It has been stated in previous chapters that (*a*) a certain cyl. at a certain distance d, corrects more As. if Cx., and less As. if Cc., than its dioptric number indicates; (*b*) a certain degree of ocular As. needs a weaker +, or stronger −, cyl. when at a distance d from the eye; (*c*) the astigmatic effect of a given cyl. differs with the power of the sph. with which it is combined; (*d*) its effect differs with the nearness of the object.

The whole subject resolves itself into calculation of the effectivities of the two principal powers, instead of that of the lens as a whole as when it is spherical. Taking the distance of the lens as being always 1·65 cm. from the refracting plane, we have 4 D. As. corrected by a +3·74 D. cyl. or a −4·3 D. cyl., or reversing the condition a +4 D. cyl. corrects 4·3 D. ocular As., and a −4 corrects 3·74 D.; the formulæ are the same as for sphericals, each principal meridian being calculated separately.

The differences that occur, owing to the combination of the cyl. with a sph., and to nearness of the object, can be best shown by a few examples, as follows. Distances of the object are taken as from the lens.

+4 D. sph. ⊂⊃ +4 D. cyl. has powers of +4 D. and +8 D., whose effectivities are +4·28 D. and +9·22, so that the As. corrected is 4·94 D.

This same combination, for vision at 33 cm., has effectivities of + 1·02 D. and + 5·45 D., the astigmatic difference being then 4·43 D.

A combination of – 4 D. sph. ⊂⊃ – 4 D. cyl. has effective values of – 3·75 D. and – 7·07 D., the As. corrected being 3·32 D.

The same lenses, for vision at 33 cm., have effectivities of – 6·27 D. and – 9·31, showing 3·04 D. As. corrected.

The higher power Cx. loses more of its effectivity, from the divergence of the light, than does the lower Cx.; the higher Cc. increases less than does the lower Cc.; so that in both these cases shown, there is less astigmatic effect in near than in distant vision.

Accommodation.—The Ac. exerted at any distance by an emmetrope is D., the dioptric expression of that distance; by an ametrope it is D – R where R is the far point in diopters; thus at 50 cm. in Em. the Ac. = 2 D. in H. 2 D. Ac. = 2 – (– 2) 4 D.; in M. 2 D. Ac. = 2 – 2 = 0. The distance of the object is taken as from the lens.

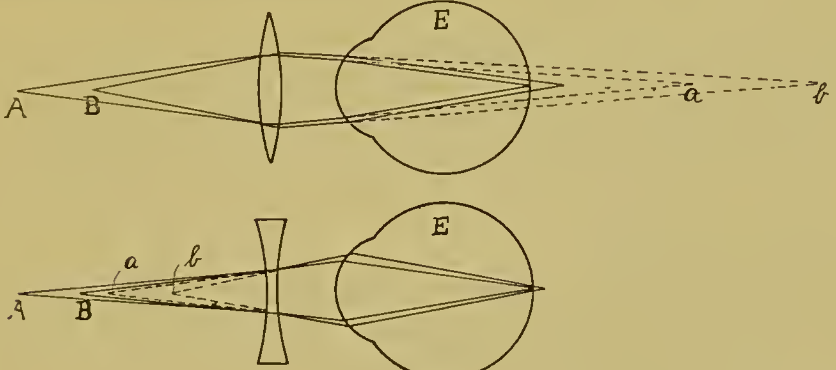


Fig. 80.

Artificial Accommodation can be obtained by altering the position of the correcting lens with respect to the principal plane of the eye, and is a question of conjugate foci.

In order that an eye may see clearly at ∞ without Ac., the principal focus of the lens must coincide with the P. R.; if the object be near, then its *conjugate* focus must coincide with the P. R. Thus what we have to find is the *change* in the image conjugate for the two positions of the object, the distance from the lens to the eye being immaterial.

In Fig. 80 let E be the eye, in one case H. and the other M., all accommodative power being supposed absent. A is an object for which the eye is corrected and *a* its conjugate image. Then, *a* is the virtual P. R. of the hypermetropic and the real P. R. of the myopic eye towards which light must converge, and from which it must diverge, respectively, in order to focus on the retina. Now suppose some other point B, whose image is at *b*, is required to be clearly seen. Obviously, in order to bring the focus again to the retina, we must restore the conjugate b to the P. R. denoted by the first conjugate a, and to do this we must either move the lens forward, or the eye backwards, by an amount equal to the distance between a and b. It is simpler to imagine the eye moved backwards because then the increase in distance between the eye and the lens will be exactly equal to the change in the conjugates a and b.

Working in dioptric distances, we know that if D be the power of the lens, A and B those of the object distances, while a and b are the image distances respectively—

$$a = \mathrm{D} - \mathrm{A} \text{ and } b = \mathrm{D} - \mathrm{B}.$$

Suppose an aphakic eye corrected by + 10 D. for vision at 100 cm. and it is required to see clearly at 50 cm.; what must be the distance between the eye and lens, the original position of the latter being at 15 mm.? We have A = 1, B = 2 and D = 10, so that—

$$a = 10 - 1 = 9 \text{ D. or } 11 \text{ cm. behind the lens,}$$
$$b = 10 - 2 = 8 \text{ D. or } 12{\cdot}5 \text{ cm. behind the lens.}$$

Therefore the eye must be receded 12·5 – 11 = 1·5 cm., so that it is 3 cm. behind the lens, in order that the P. R. may coincide with b.

If the lens were – 10 D we have—

$$a = -10 - 1 = -11 \text{ D.} \qquad b = -10 - 2 = -12 \text{ D.,}$$

so that the eye would have to be receded ·75 cm., which is the difference between 100/–12 and 100/–11.

Increasing the interval between the lens and the eye produces artificial Ac. with both + and – lenses, and enables a person to see nearer, provided, in the case of the Cx., that the object be not nearer the lens than 2 F., after completion of the movement. Reducing the distance decreases the artificial Ac., and enables a person to see farther away. Thus suppose vision was clear at 50 cm. with a + 7 D. at 1·5 cm. from the eye; what is the distance from eye to lens for vision at ∞?

$$a = 7 - 2 = 5 \text{ D.} \qquad b = 7 - 0 = 7 \text{ D.}$$

The eye must be advanced 100/5 – 100/7 = 5·7 cm., but since the original separation was only 1·5 cm., clear vision at ∞ cannot be obtained.

When the lens is strong, and near to the eye, and the distance of the object great compared with the focal length of the lens, no material error arises from taking the distance of the object as from the eye itself instead of from the lens. This approximation is not, however, permissible when the lens is weak, or the object very near or the lens far out from the eye. Also, if the latter is kept stationary, and the lens moved towards, or farther away from the object, the distance of the latter is no longer that for which Ac. is required, but in most cases with strong lenses the error is so small as to be negligible.

Optometers.

The Simple Optometer.—An optometer is an instrument for measuring indirectly the ocular refraction from an artificial P. R. and P. P. There are many different designs and some few are described in the following articles but the usual form (Fig. 81), and that to which the name is generally applied, consists of a single Cx. lens with a rod or bar, suitably scaled, on which there is a movable carrier holding a card, the latter having some fine print and an astigmatic dial. The most convenient form of optometer for the modern optician is the "Orthops" pointer.

With all optometers, however, the apparent refraction is usually too great, on account of unconscious accommodative action caused by the sense of nearness. Also the distance of clear vision is nearer if the visual acuity be lowered, independently of the refractive condition, and for these reasons a mechanical contrivance for determining the P. R. is to-day almost totally discarded, but for P. P. measurements it is indispensable and even for the P. R. is very useful, as a rough guide, in an occasional case, especially of M.

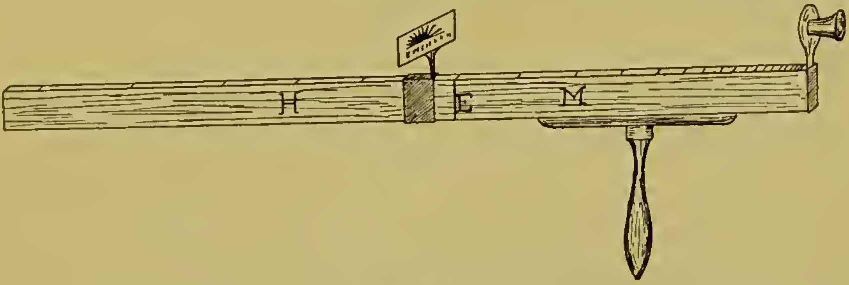


Fig. 81.

The far point is the conjugate focus of the retina when Ac. is totally relaxed and, being at ∞ in Em. and negative in H., it cannot be measured in these conditions unless the eye be made artificially myopic with a suitable + lens; in low M. the P. R. is also at too great a distance for convenient measurement, and the eye must be made more myopic. The artificial P. R. is then at F. of the lens in Em., beyond F. in H. and within F. in M. In the first case the light emerges parallel from the lens, in the second it is convergent, and in the third divergent, so that in each it is adapted for the eye under test.

The Amplitude of Ac. or the dioptric change that can be effected by the eye is—

$$A = P - R$$

where R. and P. are the far and near points in diopters, the P. R. being the minimum, and the P. P. the maximum refraction. If these are obtained with the aid of lenses, the true values are, in each case, found by deducting the dioptric power of the lens employed from the P. R. or P. P. thus found.

The "Orthops" pointer is a flat wooden bar—scaled in diopters to avoid the necessity for conversion of distances into powers—employed, in conjunction with the ordinary trial frame and lenses, for determining the P. R. and P. P., and for estimating the amplitude of accommodation and degree of refractive error. The test card is arranged with types, on the right and left, for use by the corresponding eye, and with central types for binocular use; there are two grades of type, the smaller for the near and the larger for the far point; in addition there are astigmatic discs. On the one side *A* there is a scale for *near point* measurements which also shows the age, between 10 and 55 years, and its corresponding amplitude of accommodation. On the other side the scales *B*, *C* and *D*, are used for determining the *far point*. When there is medium to high M., in which the P. R. is easily measurable without an auxiliary lens, the scale *B* is used. Scale *C* is adapted for cases of low M. or H., a + 4 D. lens being used; while *D* is employed, in conjunction with a + 8 D., when the H. exceeds 2 D.

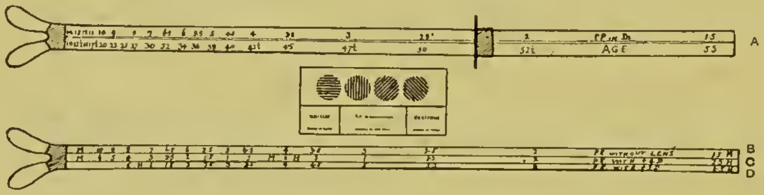


Fig. 82.—The "Orthops" Pointer.

The one eye being occluded, the carrier is first withdrawn well beyond the far point, and then slowly approached towards the eye until the print can just be read; then the P. R. is situated immediately at this distance which shows on the scale the refractive condition of the eye. A greater relaxation of Ac. and therefore a more distant P. R. is often obtained by bringing the carrier within the apparent P. R. and then very slowly moving it outwards again.

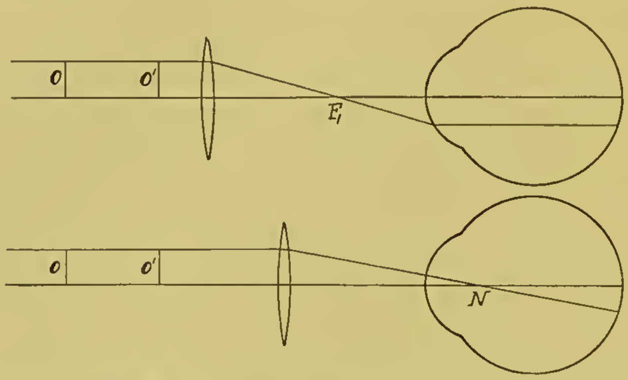
The P. R. of each principal meridian of an astigmatic eye is determined by using the scale *B*, *C*, or *D* in conjunction with the astigmatic discs in the same way as for a general refractive condition. The astigmatic discs are approached towards the eye until some lines become clear, and the position of the carrier determines the power of the eye in the meridian of least refraction, *i.e.* that of highest H. or lowest M. The position for maximum clearness of the line, at right angles to that first seen, is obtained by approaching the carrier more towards the eye, this determining the power of the meridian of greatest refraction, *i.e.* that of lowest H. or highest M. In other words the first position indicates the general error and, therefore, the spherical element of the correction; the difference between the first and the second gives the Cc. correcting cyl. whose axis corresponds to the meridian of the second line. The measurement of As. thus obtained is not very accurate and is therefore not generally employed. Thus suppose without any lens, the first line seen is vertical and indicates M. 2 D., and on approaching the carrier the horizontal line is clear at M. 5 D., the required lenses are $-2{\cdot}0$ S. ⊃ $-3{\cdot}0$ C. Ax. 180.

To use the scale *A* for near-point measurement, the closest point of distinct vision is obtained by running the carrier so near to the eye that fine type is illegible, and then slowly moving it outwards until the print can just be read. This gives the P. P. which, expressed in diopters, shows the apparent amplitude of accommodation when the distance correction is in the frame. The age which normally corresponds to the Amp. of Ac., as indicated by the P. P., being shown on the same scale, the difference between the P. P. obtained and that assigned to the age, can be seen at a glance.

If the test is made with an auxiliary lens, the P. P. shown on the scale differs from the true P. P. by the power of that lens. If the P. P. is very near, it is difficult to measure unless a Cc. lens, say, 3 or 4 D., be placed in front of the eye; on the other hand if the Ac. be very depleted a + lens is needed to bring it within a measurable distance; in both cases the power of the lens must be deducted from the position shown. Thus if the P. P. is at 5 D. with a -4 D., the actual P. P. is $5-(-4)=9$ D. If it is at the same place with a $+4$ D., the real P. P. is $5-(+4)=1$ D. Measurements of the P. P. without the distance correction are occasionally useful as described in H., spasm of Ac., etc., but if there is any uncorrected As. they are, of necessity, indefinite; the binocular P. P. may differ materially from that of each eye alone.

Allowance being made for the refractive condition, the age of a person can be roughly gauged by the P. P., and while the calculation may, in some cases, be found to be far from accurate it is often curiously exact; even when latent H. is present, the Amp. of Ac. being frequently far above the minimum, the P. P. very nearly corresponds to the latter. In old people the figures, given in the table of amplitudes, are more nearly those of the average. In ordinary subjective sight testing we really use an optometer which is 6 m. long whereby the P. R. is placed at ∞ by means of lenses and Snellen's test-types. The P. P. and Amp. of Ac. is then found by the pointer or some similar contrivance.

Badal's Optometer has some special qualities. If the lens (Fig. 84) is placed so that *F*, its focal point, coincides with the nodal point of the eye, a ray, parallel to the axis before refraction, passes, after refraction by the lens, through *N* the nodal point without further deviation, no matter what the distance of the object may be; consequently the angle under which the image is formed is always the same and there is no sense of change in the distance of the types as the carrier is moved. If the lens (Fig. 83) is placed so that *F* coincides with F_1, the anterior focal point of the eye, then a ray parallel to the principal axis of the lens, before refraction, is parallel to the principal axis of the eye after refraction. The conditions are the same as before, *i.e.* the refraction of the eye is measured with equality of size of retinal image and the sense of nearness or approach of the object is, to a great extent, eliminated. The usual lens is + 10 D. placed 115 mm. in front of the cornea or some 23 mm. less for the first-mentioned condition.



Figs. 83 and 84.—The Badal Optometer.

The lower diagram shows coincidence of F with the nodal point, and the upper the coincidence of F with F_1 of the eye.

The Young Optometer (Fig. 85) consists essentially of a single convex lens *L*, in front of which is a diaphragm having two narrow vertical slits, whose distance apart is less than the diameter of the pupil; instead of the usual card with types, the object is simply a white line *BC*. The action of the diaphragm is to produce, in the eye under test, two images of the line which apparently cross each other at the artificial far-point *A*, the conjugate focus of the retina on which the single image *A′* is formed. Any other point, as *B* or *C*, is seen double since its two images, caused by the aperture, do not unite on the retina.

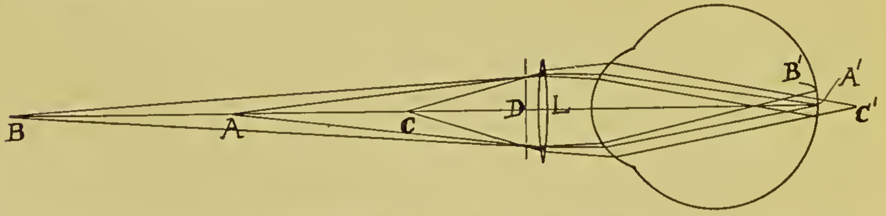


Fig. 85.—The Young Optometer.

D is the disc, and *B*, *A* and *C* are three points on a straight line. The images of *B* and *C* are seen double, while the image *A′* of the point *A* is single.

Fig. 86 illustrates the appearance of the line, and *R* the far point at which the double images apparently intersect, the latter position being indicated by a pointer moving along a suitable scale. The reading is more exact if 3 or 4 slits are employed, the crossing-point being better defined. In As. the reading, for each principal meridian, is obtained by employing the slits in these meridians. A vertical wedge-shaped slide is provided to occlude the central portion of the eye, and in this way the peripheral and central refraction can be separately determined and compared. The extreme peripheral refraction, on either side, can be found by using the most widely separated apertures to expose any of the extreme peripheral portions of the pupil, and it was in this manner that Tscherning studied the spherical aberration of the eye.

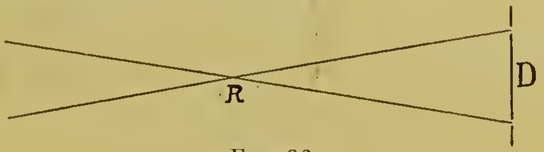


FIG. 86.

The Scheiner Disc is, in principle, similar to the Young optometer; it consists of an opaque disc, with two very small (pinhole) apertures distant from each other less than the diameter of the pupil of the eye under examination. Light from a small source at ∞ enters the eye, through the apertures, and forms two images which, if the eye is emmetropic, coincide at the retina, only one then being seen. When ametropia exists, two images are seen and these are rendered distinctive by means of a red or green glass placed over one of the apertures. If the eye be hypermetropic, the two cones of light reach the retina before uniting; the right and left cones fall on the right and left of the retina respectively, forming two *uncrossed* images which are mentally referred outwards as *crossed*, the coloured image being seen on the opposite side to the aperture having the tinted glass. In myopia the cones of light meet each other in the vitreous and form *crossed* images on the retina; the projected images are therefore *uncrossed*, the coloured image being seen on the same side as the corresponding aperture. One image therefore denotes Em., two crossed images H. and two homonymous images M. The correction is the strongest convex, or the weakest concave, that, held in front of the disc, causes the two images to be seen as one.

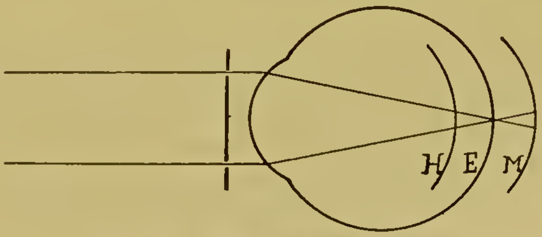


FIG. 87.—THE SCHEINER DISC.

The P. P. can be found by holding a thin object, such as a needle, at right angles to the plane of the apertures. It is then approached until a point is reached at which the accommodation fails to fuse the images, and the object is seen double, the nearest point at which a single object is seen representing the distance of the P. P. Scheiner's method is not much used to-day, owing to the difficulty in keeping the disc so adjusted that the pupil includes both apertures and other obvious reasons.

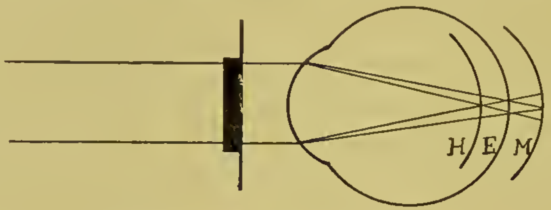


Fig. 88.—The Chromatic Disc.

The Chromatic Test, based on the chromatism of the eye (*q.v.*), can be used for the approximate determination and correction of refractive errors. The disc consists of a very deep cobalt blue glass which blocks out the central spectrum colours, and transmits only red and blue, the object viewed being a distant circular source of light about 1″ in diameter. One eye being occluded, the light, viewed through the disc, is seen by the eye under test—

In Em.	As a purple circle, often with a light blue margin.
In H.	Blue circle with a light red margin.
In M.	Red circle with a light blue margin.
In simple H. As.	Purple ellipse with red extremities.
In simple M. As.	Purple ellipse with blue extremities.
In compound H. As. ..	Blue ellipse with red extremities.
In compound M. As. ..	Red ellipse with blue extremities.
In mixed As.	A circle or ellipse, purple in centre, with extremities red in one direction and blue in the other.
In irregular As.	Irregular oval or ellipse.

The separation of the colours is, of course, due to the fact that the blue light comes to a focus sooner than the red, the aberration being emphasized in ametropia. The test is not sufficiently delicate to be of any practical utility, and generally the eye appears to possess a greater static refraction than is actually the case—in other words, the M. eye is apparently more M. and the H. eye less H. than it really is. Theoretically the lens or combination that causes the source to be seen as a circular purple disc, as in Em., is the correction of the error.

Fig. 89.—The Prisoptometer.

D the disc, *E* as seen in emmetropia, *M* as in myopia, *H* as in hypermetropia.

The Double Prism Test.—A double prism—the common edge-line of which bisects a 1/8 inch aperture in a black disc—and a circular test object is the principle of another form of optometer. The strength of the prisms, the size of the test object and the distance of the latter must all be such that, when an emmetrope looks through the aperture, the two images seen just touch each other. If they overlap, there is M.; if they are separated there is H. On revolving the disc, if the overlapping or separation is greater at some positions than at others, there is astigmatism and the lenses that make the two images just touch, during a complete circuit of the disc, is the correction required.

Other Forms of Optometers which are most worthy of note are :—

Two convex lenses forming a telescope arrangement, as in the Hirschberg.

A convex and a concave lens, like an opera-glass system, as in the refractometer.

An arrangement of a Cc. ophthalmoscopic mirror and a convex lens for seeing a real image of the retinal image, as in the Schmidt-Rimpler.

Optometric Calculations.

The measurements, as indicated in this article, give the *apparent* or *manifest* refractive condition and A. the Am. of Ac. From the former the correcting lens for distance can be estimated and from the latter the additional reading glasses can be calculated. Thus suppose the P. P. is at 20 cm. = 5 D. and the eye is respectively H. 2 D., Em. and M. 2 D.; then—

In H. 2 D. $A = P - R = 5 - (-2) = 7$ D.
In Em. $A = P - R = 5 - 0 = 5$ D.
In M. 2 D. $A = P - R = 5 - 2 = 3$ D.

So that when an ametropic condition is fully corrected, the P. P. shows the actual Amp. of Ac.; if the manifest error is corrected the P. P. shows the available Amp. of Ac.

If three eyes be respectively H. 3 D., Em., and M. 3 D. and each has an Amp. of Ac. = 6 D., then—

In H. 3 D. $P = A + R = 6 + (-3) = 3$ D.
In Em. $P = A + R = 6 + 0 = 6$ D.
In M. 3 D. $P = A + R = 6 + 3 = 9$ D.

More generally P. or R., or both, are found with the aid of lenses. If both be obtained with the same lens, as may be done in many cases, using the one side of the pointer for the P. P. and the other for the P. R., no further calculation is necessary for obtaining A., beyond taking the difference between the P. P. and P. R., since both points are an equal number of diopters nearer or farther away owing to the action of the lens.

Thus if with +6 D. the P. P. is at 12·5 cm. and the P. R. at 100 cm., then A. = 8 − 1 = 7 D.

The P. P. is 12·5 cm. or 8 D.; the true P. P. is 8 − 6 = 2 D.

The P. R. is 100 cm. or 1 D.; the true P. R. is $1 - 6 = -5$ D.
Then $A = 2 - (-5) = 7$ D. the same as shown before.
The optical condition is H. 5 D. as indicated by the negative P. R.

When different lenses are used to find the near and far points, the actual values of the latter must be calculated separately and the difference between them taken for the Amp. of Ac. The following are examples in which P. and R. are given in diopters only :

With a + 3 D., the P. R. shows 5 D. and with − 1 D., the P. P. shows 8 D.; then—

The P. R. is $5 - 3 = +2$ D. = M. 2 D.
The P. P. is $8 - (-1) = 9$ D.
The Amp. Ac. $= 9 - 2 = 7$ D.

With a + 6 D., the P. R. shows 1·5 D. and with − 3 D., the P. P. shows 3·5 D.; then—

The P. R. $= 1{\cdot}5 - 6 = -4{\cdot}5$ D. = 4·5 D. H.
The P. P. $= 3{\cdot}5 - (-3) = 6{\cdot}5$ D.
The Amp. Ac. $= 6{\cdot}5 - (-4{\cdot}5) = 11$ D.

In the foregoing if P.′ and R.′ are the near and far points, found with the aid of the lens D, while P and R are the true near and far points, we presume that—

$$P = P' - D \quad R = R' - D \quad \text{and} \quad A = P' - R' = P - R.$$

While this is sufficiently exact for practical purposes, it is not actually true on account of the effectivities of the lenses, as shown in the next article.

True Optometric Findings.—The interval between the lens and the eye, and the varying distances of the object, cause changes in the effective value of the lens on the optical system of the eye. When the lens D is at a distance from the principal plane, the true near and far points P. and R. are the conjugate foci of the new positions P.′ and R.′, from which the light must diverge to the lens in order that, after refraction by the latter, it may enter the eye proceeding from or towards the true P. P. or P. R. For convenience, and as in previous calculations the distance of the lens from the refracting plane is taken to be 1·65 cm., but the fraction representing any other distance can be substituted, if necessary, in the following formulæ, where all the terms are in diopters.

$$R = \frac{R' - D}{1 + \cdot 0165\,(R' - D)} \qquad P = \frac{P' - D}{1 + \cdot 0165\,(P' - D)}$$

$$A = P - R \qquad A' = P' - R'$$

Thus suppose with a + 5 D. lens, we obtain $R' = 3$ D. and $P' = 9$ D. By ordinary calculations, we should get—

$$3 - 5 = -2 \text{ D. or 2 D. H. and } A' = 9 - 3 = 6 \text{ D.}$$

The true values are—

$$R=\frac{3-5}{1+\cdot0165\times(-2)}=-2\cdot07\text{ D.}\qquad P=\frac{9-5}{1+\cdot0165\times4}=3\cdot75\text{ D.}$$

$$A=3\cdot75-(-2\cdot07)=5\cdot82\text{ D.}$$

If, with a − 5 D., we can get $R'=7$ and $P'=11$, *i.e.* there is apparently M. 2 D. with $A'=4$ D. But—

$$R=\frac{7-5}{1\times\cdot0165\times2}=1\cdot93\text{ D.}\qquad P=\frac{11-5}{1+\cdot0165\times6}=5\cdot46\text{ D.}$$

$$A=5\cdot46-1\cdot93=3\cdot53\text{ D.}$$

Knowing the values of R and P, we can get—

$$R'=D+\frac{R}{1-\cdot0165\,R}\qquad P'=D+\frac{P}{1-\cdot0165\,P}$$

and, since, in the ordinary way, the estimated far and near points are found from $R'-D$ and $P'-D$, we can see that *it is the distance of the lens from the eye only, that affects the measurement of a given far or near point.*

In H. 2 D. with an Amp. Ac. = 6 D., and with a + 5 D. lens, by the methods indicated we find that—

$$R'=-1\cdot93\text{ D.}\qquad P'=3\cdot75\text{ D.}\qquad A'=5\cdot68\text{ D.}$$

In a case of M. 2 D. with an Amp. of 6 D., and a + 5 D. lens, we find—

$$R'=2\cdot07\text{ D.}\qquad P'=9\cdot22\text{ D.}\qquad A'=7\cdot15\text{ D.}$$

The differences between true and optometric measurements are neglible in ordinary defects; and so long as *d*, the distance of the lens, is equal to F_1 of the eye, the optometric P. R. is the same numerically as the correcting lens.

Astigmatic Lenses.—Light from a distant luminous point, refracted by a sph. lens, has a point for its image; refracted by an astigmatic, or sph.-cyl., lens its image lies in two focal lines, at different distances, which are mutually at right angles, and whose directions correspond to the principal meridians of the lens. The principal meridians are those containing the highest and lowest power that the lens possesses, so that in the case of a plano-cyl., the one power is 0. The light, from each point of the object forms focal lines at the focal distances, and the collection of the lines form bands of light, which are narrow as the focal distances are short. These *bands* are commonly termed the *focal lines.*

Each focal line is at the focal distance of the power which produces it, and lies in the meridian at right angles to that containing the power to which it pertains. Thus in + 3 D. sph. + 2 D. cyl. axis 90°, the principal powers are + 3 D. at 90° and + 5 D. at 180°; the first focal line being Ver.

at 20 cm., and the second Hor. at 33 cm. All the light from a luminous point, after refraction, passes through a Ver. line at 20 cm. then, converging vertically and diverging horizontally, it all passes through a Hor. line at 33 cm.

The distance between the focal lines is called the *interval of Sturm*, and it represents the degree of As. in a lens or an eye, the dioptric difference between its two extremities being the degree of As. in diopters, *i.e.* the cylindrical element. Anywhere in the interval of Sturm the light forms an elliptical disc of confusion whose two axes correspond to the meridians of the focal lines, but at one position the axes are of equal length and form the *circle of least confusion ;* also at two different positions, the diameter of the ellipse is reduced in one direction to zero, and in the other to its maximum length, and these are the focal lines themselves. Calculations on Sturm's interval are shown in the next article.

In astigmatic lenses, the principal powers are those of the meridian containing the axis of the cyl. and of the meridian at right angles to the axis. When the two components are of the same nature, *i.e.* both Cx. and both Cc., the lower power corresponds to the axis of the cyl., but if the two components are of opposite nature, *i.e.* Cx. sph. ⬭ Cc. cyl. or Cc. sph. ⬭ Cx. cyl., the higher power corresponds to the axis. If, however, the two *powers* are of opposite nature, either the smaller or greater power may correspond to the axis. For calculations on cylindrical lenses, their transpositions, etc., see "General and Practical Optics." Any sph.-cyl. has its equivalent in two crossed cyls. whose axes are at right angles to each other and *vice versa*. Even obliquely crossed cyls. are always equivalent to a crossed cyl. or a sph.-cyl.

Calculation of the Interval of Sturm.

Assuming the normal eye to have 45 D. posterior refractive power, let an example be taken of one which is myopic 2 D. and 5 D., respectively, in the two principal meridians. Assuming further that the refractive errors are due to curvature, the two focal lines F′ and F″ lie respectively at 20 and 21·5 mm. behind the principal plane of the eye. It may be taken that the aperture of the pupil is 3·7 mm. in diameter, and that it lies in the refracting plane. An example is also given of a + 6·0 S ⬭ + 2·0 C, that is, one having principal powers of + 6 D. and + 8 D., with a circular aperture of 25 mm.

S is the length of the interval of Sturm.

p is the size of the lens aperture, or of the pupil.

L′ and L″ are the lengths of the focal lines, F′ and F″ their distances from the aperture.

a and b are the distances of the circular disc of confusion from L′ and L″ respectively.

B is the size of the circular disc of confusion.
d is the distance of B behind the lens.

	Eye M. 2 D. and 5 D.	Lens Powers +6 and +8.
	Mm.	Mm.
$S=F''-F'$	$21{\cdot}5-20=1{\cdot}5$	$166-125=41$
$L'F''=L''F'$		
$L'=\frac{pS}{F''}$	$\frac{3{\cdot}7\times1{\cdot}5}{21{\cdot}5}=\cdot2581$	$\frac{25\times41}{166}=6{\cdot}19$
$L''=\frac{pS}{F'}$	$\frac{3{\cdot}7\times1{\cdot}5}{20}=\cdot2775$	$\frac{25\times41}{125}=8{\cdot}2$
$\frac{a}{b}=\frac{L'}{L''}=\frac{F'}{F''}$	$\frac{\cdot2581}{\cdot2775}=\frac{20}{21{\cdot}5}$	$\frac{6{\cdot}19}{8{\cdot}2}=\frac{125}{166}$
$a=\frac{SF'}{F'+F''}$	$\frac{1{\cdot}5\times20}{20+21{\cdot}5}=\cdot7229$	$\frac{41\times125}{125+166}=17{\cdot}61$
$b=\frac{SF''}{F'+F''}$	$\frac{1{\cdot}5\times21{\cdot}5}{20+21{\cdot}5}=\cdot7791$	$\frac{41\times166}{125+166}=23{\cdot}39$
$a+b=S$	$\cdot7229+\cdot7791=1{\cdot}5$	$17{\cdot}61+23{\cdot}39=41$
$B=\frac{aL''}{S}=\frac{bL'}{S}$	$\frac{\cdot7229\times\cdot2775}{1{\cdot}5}=\cdot134$	$\frac{17{\cdot}61\times8{\cdot}2}{41}=3{\cdot}522$
$d=\frac{2F'\ F''}{F'+F''}$	$\frac{2\times20\times21{\cdot}5}{20+21{\cdot}5}=20{\cdot}7229$	$\frac{2\times125\times166}{125+166}=142{\cdot}61.$

If the pupil, or the aperture of the lens, is larger or smaller, L′, L″ and B vary in proportion.

Adding Lenses.—It is often very convenient to add a lens to a combination in the trial frame, instead of changing one or both lenses. The effect of adding a sph. is simply to increase or decrease the original sph. element, the cyl. remaining unchanged; when a cyl. is added, with its axis corresponding to that of the original, the latter is similarly altered while the sph. is not. Other additions result as follows :—

With a + sph. ⊂⊃ + cyl.
Adding a + cyl. at right angles *increases* the sph. and *reduces* the cyl.
Adding a – cyl. at right angles *reduces* the sph. and *increases* the cyl.
With a – sph. ⊂⊃ – cyl.
Adding a + cyl. at right angles *reduces* the sph. and *increases* the cyl.
Adding a – cyl. at right angles *increases* the sph. and *reduces* the cyl.
With a + sph. ⊂⊃ – cyl.
Adding a + cyl. at right angles *increases both sph. and cyl.*
Adding a – cyl. at right angles *reduces both sph. and cyl.*
With a – sph. ⊂⊃ + cyl.
Adding a + cyl. at right angles *reduces both sph. and cyl.*
Adding a – cyl. at right angles *increases both sph. and cyl.*

An example will render this clearer; it is merely a matter of transposition to find out the change of difference between the principal powers. Thus suppose a +1·0 S. ○ + 1·0 C. Ax. 90°.

Added Lens.	Result.
+ ·5 cyl. ax. 90°.	+1 sph. ○ +1·5 cyl. ax. 90°.
− ·5 cyl. ax. 90°.	+1 sph. ○ + ·5 cyl. ax. 90°.
+ ·5 cyl. ax. 180°.	+1·5 sph. ○ + ·5 cyl. ax. 90°.
− ·5 cyl. ax. 180°.	+ ·5 sph. ○ +1·5 cyl. ax. 90°.
+1 cyl. ax. 90°.	+1 sph. ○ +2 cyl. ax. 90°.
− 1 cyl. ax. 90°.	+1 sph.
+1 cyl. ax. 180°.	+2 sph.
− 1 cyl. ax. 180°.	+2 cyl. ax. 90°.

The application of these rules is, sometimes, very useful in practice in quickly determining whether more sph. and less cyl., or less sph. and more cyl., etc., would be better in any particular test. In many trial cases, there is supplied a special cross-cyl. giving opposite powers, of, say, − ·25 and + ·25 or − ·50 and + ·50, which serves a similar purpose, but equally good results can be secured by the intelligent application of weak plano cyls. as described above. In these calculations changes due to effectivity have not been considered.

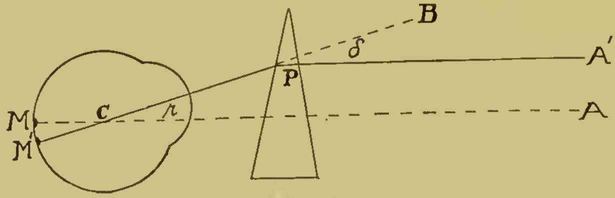


FIG. 90.

Effectivity of Prisms and Prismo-Sphericals.

The True Effects of Prisms and Prismo-Sphericals on the Fixation Lines.—Although, for practical purposes, it suffices to reckon the deviation of the visual axis as equal to that caused by the prism, yet actually this is not usually the case. The deviation of the eye is equal to the angular deviation of the prism only when a plano-prism is employed and the object viewed is at ∞.

Prism and Object at ∞.—In Fig. 90 let *C* be the centre of rotation of an eye, in front of which is a plano prism. Then parallel light, from an object *A* at ∞, will be deviated through the angle δ, so that the eye must rotate through the angle r in order to receive the image on the macula M'. Since the angles $\delta = A'PB$ and $r = ACB$ are equal, it follows that the angular rotation of the visual axis is equal to the angular deviation of the prism.

Prism and Object at a Near Distance.—Let *A* in Fig. 91 be the object at a finite distance and *BPC* the ray which, after refraction, passes through the centre of rotation *C* of the eye. Then the total deviation δ of the prism is

APB, while *ACB* is the angle r through which the eye is rotated in order to bring the macula M' to the image. The angle r is less than δ, so that the deviating effect of a prism on the eye is less than in distant vision ; or if a certain deviation of the eye, when viewing an object at a given distance, is needed, a prism of greater angular deviation is required.

Let b be the distance of the object A to the prism, and let the distance of the centre of rotation C to the prism be taken as 2·5 cm. Then if we express the displacement t, of A, caused by the prism, in cm. and the distance b in metres, the actual power of the prism in prism diopters is t/b. But the effect on the eye is that of t/AC and since $AC = b + {\cdot}025$ metres we get, as the actual effect of the prism of the eye—

$$\frac{t}{b + {\cdot}025}$$

Since $t/b = \Delta$ and $t/(b + {\cdot}025) = \Delta'$ where Δ is the prismatic power in prism diopters and Δ' is its effective power on the eye, we get the equation—

$$\Delta b = \Delta' \ (b + {\cdot}025),$$

whence

$$\Delta = \frac{\Delta' \ (b + {\cdot}025)}{b} \quad \text{or} \quad \Delta' = \frac{\Delta b}{b + {\cdot}025}$$

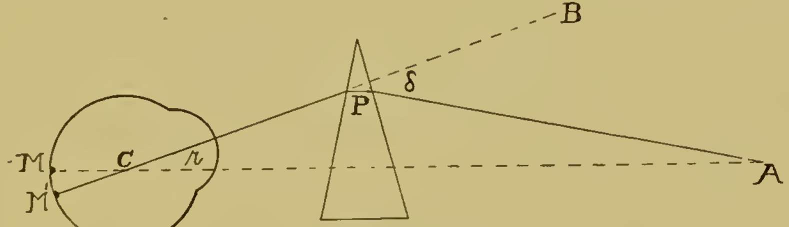


Fig. 91.

Suppose the object to be at 20 cm. in front of a 5$^{\Delta}$. The effect on the eye will be—

$$\Delta' = \frac{5 \times {\cdot}20}{{\cdot}20 + {\cdot}025} = 4{\cdot}44$$

Thus the power of a prism to cause deviation of the visual axes is less as the object viewed is near, and if a certain prismatic effect is required in near vision, a stronger prism must be employed. Suppose 5$^{\Delta}$ effect is needed for vision at 40 cm. from the prism ; then—

$$\Delta = \frac{5 \ ({\cdot}40 + {\cdot}025)}{{\cdot}40} = 5{\cdot}3$$

Deviation of Prismo-Sphericals for Distant Objects.—If a *spherical lens is decentred* (*i.e.* a virtual prism) its deviating effect is precisely the *same as if it were combined with a certain prism*, the prismatic effect being calculated from the distance between the optical and geometrical centres. The direction of the visual axis, when looking through a prismo-spherical, is not, however, through the geometrical centre of the lens, but through some other point, with the result that the prismatic effect of a Cx. sphero-prismatic lens is greater, and that of a Cc. is less, than that indicated by the *actual* or *virtual* prism.

In Fig. 92 the geometrical centre of the lens is *G* and the optical centre is *O*. When the object is at ∞ the initial direction of the eye is *CG*, but with the lens in position the light is deviated and tends to converge to the focus

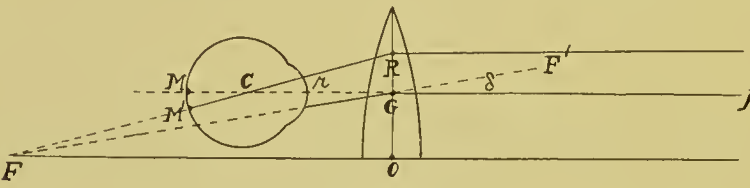


Fig. 92.

F, and, in order to receive the image on the macula, the eye must deviate through the angle *r*. Owing to the appreciable interval between the lens and the centre of rotation *C*, the eye must turn to receive the more strongly deviated ray *RC*. The actual prismatic deviation at the geometrical centre *G* is represented by the angle $\delta = AGF'$ which is less than the angle $r = ACR$. Therefore, with a convex sphero-prism the deviation of the eye is *greater* than the prismatic effect calculated for the geometrical centre of the decentred lens, or that of the added prism.

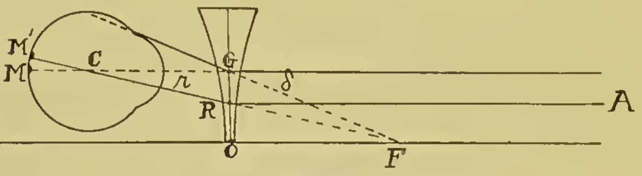


Fig. 93.

With a concave prismo-spherical we have the reverse condition. Here (Fig. 93) $r = GCR$, the angular deviation of the eye, is less than δ, the calculated deviation produced at the geometrical centre by the decentration or by the added prism.

It will be seen that the increase or decrease in prismatic effect is due to the effectivity of the lens, resulting from its position in front of the eye. This separation causes the visual axis to be directed along a line represented by the direction, after refraction, of some ray other than that which passes through the geometrical centre of the lens. Now we know that if C be the decentration of a lens in cm. and D its dioptric power, the prismatic effect in the region of the new geometric centre is—

$$\Delta = DC$$

We also know that the effectivity D_E of a lens when advanced a distance d in metres is—

$$D_E = \frac{D}{1 - dD}$$

Taking $d = 2{\cdot}5$ cm. as before, the effectivity in the plane of the centre of rotation of the eye is—

$$D_E = \frac{D}{1 - {\cdot}025\ D}$$

and if C be the actual decentration in cm., the prismatic effect at the centre of rotation is—

$$\frac{DC}{1 - {\cdot}025\ D}$$

But the expression DC is the nominal prismatic effect which is represented by Δ. Therefore the effective prismatic power Δ' of a decentred lens, or of a lens combined with a prism, 2·5 cm. from the centre of rotation of the eye is—

$$\Delta' = \frac{\Delta}{1 - {\cdot}025\ D} \quad \text{or} \quad \Delta = \Delta'(1 - {\cdot}025\ D)$$

For example, a +10 D. lens is decentred ·5 cm. for the nominal power of $10 \times {\cdot}5 = 5^\Delta$ or it is combined with a prism of 5^Δ; what is the actual effect Δ' on the eye for distant objects ?

$$\Delta' = \frac{5}{1 - {\cdot}025 \times 10} = 6{\cdot}66$$

Or, conversely, what prism must be added to a +10 D. lens in order to obtain an actual effect of 5^Δ ?

$$\Delta = 5(1 - {\cdot}025 \times 10) = 3{\cdot}75.$$

Or the lens must be decentred $3{\cdot}75/10 = {\cdot}375$ cm. and not ·5 cm. as is usually calculated.

A −10 D. lens combined with a 5^Δ prism has the effect of—

$$\Delta' = \frac{5}{1 - {\cdot}025(-10)} = 4$$

Or to obtain an actual effect of 5^Δ there must be added to it—

$$\Delta = 5[1 - {\cdot}025 \times (-10)] = 6{\cdot}25$$

Prismo-Sphericals and Near Objects.—When the object is at a finite distance the same arguments, in general, apply but instead of D, the power of the lens, we must consider the conjugate dioptric power for a distance f_1 in cm. of the object.

Let the object f_1 be beyond the focal distance (Fig. 94) of a convex sphero-prism, such that f_2 is the conjugate image. Then, as before, the angle $r = f_1CR$ represents the rotation of the eye which is greater than the deviation $\delta = f_1Gf'_2$ at the geometrical centre G. If, however, the object be within the focal distance, the effect on the eye is less than that at G, while if the object be at the focal distance of the lens, the prismatic effect is that of the actual or virtual prism.

As will be seen from the next diagram (Fig. 95) the ocular deviation, with a concave prismo-sphere, is always less than the nominal deviation.

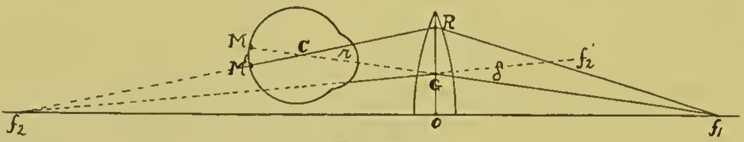


FIG. 94.

Here $f_1Gf_2 = \delta$ the lens deviation, and $f_1Cf_2 = r$ the ocular rotation, and it will be seen that r is less than δ for any distance of the object. To calculate the actual prismatic effect on the eye, in near vision, caused by a prism combined with a sphere, or by a decentred lens, we have to substitute for D, the power of the lens, the conjugate focal power corresponding to a distance in cm. of the object. Taking, as before, the distance of the centre of rotation behind the lens as 2·5 cm., the calculations simplify to the following formulæ :—

$$\Delta' = \frac{\Delta}{1 - {\cdot}025\text{ D.} + 2{\cdot}5/f_1} \quad \text{or } \Delta = \Delta'\,(1 - {\cdot}025\text{ D.} + 2{\cdot}5/f_1)$$

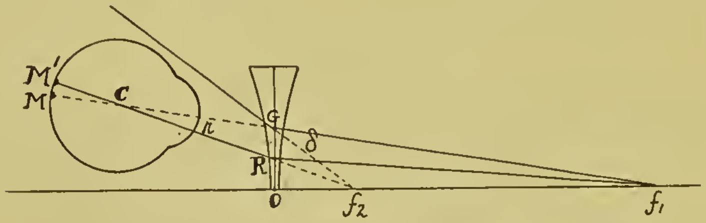


FIG. 95.

For example, a +10 D. lens is decentred ·5 cm. or it is combined with a 5Δ. What is its effect, in prism diopters, on the eye if the object be at 20 cm.?

$$\Delta' = \frac{5}{{\cdot}75 + {\cdot}125} = \frac{5}{{\cdot}875} = 5{\cdot}7$$

Conversely what prism must be added to a +10 D. lens to obtain the effect of 5Δ when the object is at 20 cm.?

$$\Delta = 5\,({\cdot}75 + {\cdot}125) = 4{\cdot}375$$

Or the necessary decentration would be $4{\cdot}375/10 = {\cdot}4375$ cm.

With a − 10 D. lens combined with 5^{Δ} and the object at 20 cm. we get—

$$\Delta' = \frac{5}{1{\cdot}25 + {\cdot}125} = 3{\cdot}63$$

Or to obtain the true effect of 5^{Δ} for vision at 20 cm. the prism added to − 10 D. would be—

$$\Delta = 5\ (1{\cdot}25 + {\cdot}125) = 6{\cdot}875.$$

Other Prismatic Changes.—In the previous articles the lenses are presumed to be accurately centred for distance, or near work as the case may be, but prismatic effects are introduced or changed by the action or relaxation of convergence and also by lateral and vertical rotation of the eyes; these effects and those due to lens displacement are quite independent of, and are additional to, those due to nearness of object and to the combination of a spherical and a prism or to original decentration of lenses.

Prismatic Effect due to Convergence.—If a pair of lenses properly adjusted for distant vision are used for near work, the eyes being then converged, each lens is decentred out, the effect being negative, or base out, with Cx. lenses and positive, or base in, with concaves. The total prismatic effect, caused by convergence, calculated in the ordinary way is—

$$\Delta = (D_1 + D_2)\ C$$

where D_1 and D_2 are the powers of the two lenses and C the displacement in cm. of the one visual line in the plane of the lenses. The above is nominal and the actual effect Δ' would have to be found by the formulæ previously given. If the reading distance be 33 cm. the displacement of each visual line is approximately ·15 cm. and the prismatic effect produced is $\Delta = {\cdot}15$ D., where D is the horizontal power of the lens.

If for example the two lenses are + 3 D., then—

$$\Delta = (+3+3) \times {\cdot}15 = {\cdot}9$$

If the one lens is Cx. and the other Cc. the effect on convergence is lessened, and if they are equal as, say, + 3 D. and − 3 D. their sum is 0 and, although they cause lateral displacement of the visual axes, they have no effect on convergence.

If prisms added to sphericals, or decentred sphericals, geometrically centred for distance, are used in near vision, the prismatic effect is considerably changed by the convergence, according as the prisms and lenses are + or −. These last-mentioned changes, from the effects in distant vision, and due to convergence, are that—

+ lenses with − prisms (base out)	have increased effect.
+ lenses with + prisms (base in)	have decreased effect.
− lenses with + prisms	have decreased effect.
− lenses with − prisms	have increased effect.

Since, as shown in the previous articles, Cx. lenses cause increased effect when the object is beyond F, and decreased when the object is within F, while Cc. lenses always cause a decreased effect, these changes may be still further increased or they may be decreased, neutralized or reversed by non-coincidence, due to convergence or otherwise, of the visual lines with the geometrically central lines of the lenses.

Prismatic Effect due to Rotation.—If lenses are centred when the eyes are directed straightforwards to an object at ∞, prismatic effect is introduced on laterally rotating the eyes. The effect varies as the lenses are strong or weak, of equal or unequal powers, and of similar or dissimilar nature. The effect also varies as lateral or vertical rotation occurs in convergence, and as the point of convergence is near, the two visual lines, of course, being equally displaced on rotation. If D_1 and D_2 be the two lenses and C the displacement in cm. of each visual line in the plane of the lens, the horizontal effect when looking sideways at a distant object, or the vertical effect when looking up or down, is $\Delta = (D_1 \sim D_2)\, C$.

This effect, on looking sideways, or upwards or downwards, results from both lenses being decentred to the right, left, down or up. If the lenses are similar and equal, $D_1 \sim D_2 = 0$, and they merely cause both eyes to rotate equally more, or less, than they would do if there were no lenses before them, and since the action is harmonious it does not cause strain on the muscles. If the lenses are unequal in power and especially if the one is Cx. and the other Cc., there is effect on convergence when the eyes are laterally displaced, since the difference between D_1 and D_2 is no longer 0. In addition there is an effect on the vertical muscles.

Thus suppose O. D. = + 1 S. and O. S. = − 4 S. and the eyes are lowered and turned to the right each ·5 cm. The difference being 5 D., the Hor. effect is $5 \times {\cdot}5 = 2{\cdot}5\ \Delta$ base in and the Ver. effect is $2{\cdot}5\ \Delta$ base down O. S. If the lenses were O. D. + 1 S. and O. S. + 4 S. the Hor. effect would be that of a $(4 \sim 1) \times {\cdot}5 = 1{\cdot}5\ \Delta$ base out and the Ver. effect would be $1.5\ \Delta$ base up O. S.

When looking obliquely at a near object there is both convergence and lateral displacement, the latter being greater for the one eye than for the other and the total effect of the two varies accordingly. The total effect is that due to rotation plus that due to convergence, each being calculated separately; the one may increase, decrease or neutralize the other.

Further Effects.—Prisms are numbered and their power considered according to their minimum deviation, but they have an increased effect on the eyes when the incidence of the light is other than that of minimum deviation. This has particular influence in near vision and when the prisms are base out; also the spherical aberration of a decentred lens increases the prismatic action over and above the calculated effect.

Effects due to Frames.—Similar effects to those produced by convergence and rotation, may be caused by badly fitting frames, these being too narrow or too wide, too high or too low for the eyes when in use. Again the eyes have been presumed to be equally displaced on convergence or rotation, both lenses being centred for some one position of the visual axes; this does not, of necessity, occur since the distance of each eye from the median line may not be the same.

Total Effects.—The various effects due to different causes are bewilderingly great, but may generally be ignored in the case of weak lenses and weak prisms and, moreover, they frequently counteract one another to some degree. The variations in effect point, however, to the necessity for—

1. Testing muscles with corrective lenses, and at the required distances.
2. Fitting frames, as accurately as possible, for the distance at which they are mostly used.
3. Fitting frames so as not to throw strain on *weak* muscles.
4. Looking for the cause of continued asthenopia in the fit of the frame.

Calculations for the conversion of prism power from one notation to another, for the decentring of sphericals and cylindricals, for resultant prisms, for resultant decentrations, etc., are to be found in "General and Practical Optics."

CHAPTER XVII

KERATOMETRY

OPHTHALMOMETRY or keratometry is the measurement of corneal curvature and especially the *difference* of curvature existing on an astigmatic cornea. The latter, having a brilliant reflecting surface, acts as a convex mirror and the laws governing the conjugate foci of mirrors may be applied to the cornea itself.

Let *MM'* be any convex mirror, *AB* an object and *A'B'* its virtual image. Let f_1 and f_2 be their respective distances from the mirror of which *C* is the centre of curvature and r is the radius. Then we have—

$$\frac{f_2}{f_1}=\frac{A'B'}{AB}=\frac{I}{O}.$$

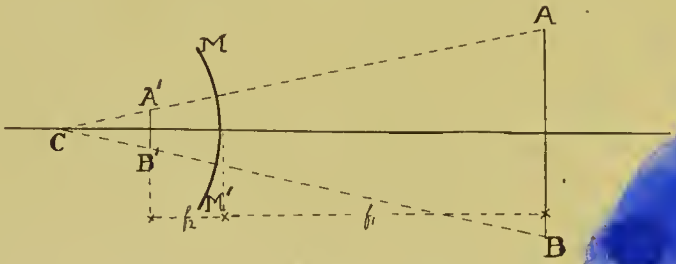


FIG. 96.

But if the mirror *MM'* is of great curvature like the cornea, and the object *AB* at a great distance compared with f_2, we may assume that *A'B'* is formed at the principal focus. We may therefore write—

$$f_2=F=\frac{r}{2} \qquad \therefore \frac{r}{2f_1}=\frac{I}{O}$$

whence

$$r=\frac{2f_1 I}{O}$$

Thus knowing the distance and size of the object, and the size of the image, we can calculate the radius of curvature of the cornea under consideration. Then, having given the radius of the cornea and its index of refraction we can calculate D_A the anterior focal power, in terms of which all ophthalmometers are scaled, the combined cornea and aqueous being considered as a single refracting surface.

The anterior corneal focal power is represented by the equation—

$$D_A = \frac{1000\ (\mu - 1)}{r}$$

where r is the radius and μ the mean index of the cornea and aqueous. It is customary to take the index as 1·3375 so that, from the above equation, a radius of 7·5 mm. corresponds to a power of exactly 45 D. This is convenient, because the instrument can be easily checked by a standard sphere of 15 mm. diameter. The following table, first constructed by Javal and Schiotz, gives the radii corresponding to a few powers, as calculated from the above expression :—

Powers in D.'s ..	40	41	42	43	44	45	46	47	48	49	50
Radius in mm. ..	8·44	8·23	8·04	7·85	7·67	7·50	7·34	7·18	7·03	6·89	6·75

The average radius of curvature is said to be about 7·8 mm., corresponding to a power of about 43 D., and most corneæ will be found to possess approximately this curvature. It is rare to find the power dropping below 40 D., or rising higher than 48 D., but readings may range from 38 D. to 50 D. in eyes not markedly ametropic. The curvature depends upon the general development of the eye; thus naturally large emmetropic eyes have a lower corneal curvature than small emmetropic eyes, but in using the ophthalmometer it is as well to habitually note the general curvature, as well as the astigmatism; the results are useful in furnishing data for averages and other interesting points, but are not indicative of the general Am.

In Fig. 96, the object AB, used to measure the corneal power with the single position keratometer, is termed the *mire*; in the two-position instruments two objects or mires, corresponding with the extremities A and B, are employed. The size of the image $A'B'$, being inversely proportional to the corneal curvature, is small as the latter is high and *vice versa.* By means of some device, the image is doubled and the doubling, together with the size and distance of mire, are so arranged that the extremity A' of the one image is brought into contact with B' of the other, when the curvature is normal. They will then separate when, owing to a high curvature, the images are smaller and will overlap when, on account of a lower curvature, they are larger. When they thus overlap or separate, contact can be obtained by increasing or decreasing the distance between the mires, or by increasing or decreasing the amount of doubling. This point is best illustrated by means of the following diagrams, which are exaggerated for the purpose of illustration.

Let the mire be of such a form that its general outline is circular, and we will suppose that exact contact M_1 (Fig. 97) of the doubled images is obtained with a certain curvature. If now the latter be decreased the images will become larger and their extremities overlap as in M_2, while if the curvature increases the images will become smaller and will therefore separate as in M_3; for convenience actual change in the sizes of the images has been omitted from the diagram. But for purposes of observation it is necessary to have some definite reference, or contact points, which, in this instance, take the form of small cross limbs L_1 at right angles to the long diametral limbs L_2, and it is very important to remember that, owing to their initial position, we may get an apparent contradiction of the above statement. For example, if the short limbs are *uncrossed* to start with, they approach, or tend to overlap, when the curvature is low and thus conform to the rule first given; but if they are *crossed* or overlapped at first, as in M_2, a further decrease of curvature will cause them to separate, which at the first glance might appear to correspond to increased curvature. Actually, however, the separation is merely the result of still further increase in the size of the image. Fig. 97 represents the mire used in the Gowlland "New" Keratometer. In the two mire ophthalometers, such as the Ettles-Curties, the doubling is generally so arranged that the central images are crossed, so that an overlapping corresponds to an increase of curvature and *vice versa*. In this case, it is the inner sides of the images that are turned towards each other.

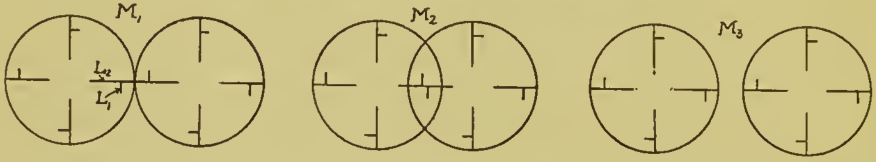


FIG. 97.

If now we have an astigmatic cornea and secure contact of the images in one principal meridian we shall, if the other meridian is of different curvature, get an overlapping or separation in this second meridian, and the amount of movement of the mires, or of the doubling apparatus, necessary to secure recontact of the images is made to indicate directly the astigmatic difference.

We may roughly class all ophthalmometers under two main heads, *i.e.* those in which the doubling apparatus is fixed and the mires movable, the reading being made on the arc bearing the mires; and those in which the mires are fixed and the doubling variable by movement of the doubling apparatus along, or across, the axis of the telescope, the reading being indicated on a dial. The doubling may be obtained in various ways as, for instance, from a double prism or from the parallel plates first employed by Helmholtz; these latter, when placed obliquely but in opposite directions, have the effect of laterally displacing the images, and their superiority over prisms lies in their better definition and freedom from chromatic aberration. Sometimes the plates are inclined towards each other in the form of a wide V, so that each causes an outward displacement of the image. Lenses have also been employed in various ways; if a convex spherical be split, a strip removed from the centre and the halves recemented, it will project a double image; or the two halves entire may be slid laterally one over the other to cause displacement. One of the best methods is that of the Wollaston prism, as found in the Javal and the Ettles-Curties ophthalmometers; it consists of two separate prisms of quartz, the one having its edge parallel to the axis of the crystal, and the other with its edge at right angles thereto, so that, when the prisms are cemented along their hypothenuses to form a rectangular slab, the light incident normally to one face emerges from the other doubly refracted into two equally divergent beams.

The three essential parts of a keratometer are the telescope, the object or mires, and the doubling apparatus. The cornea under observation is approximately at the one symmetrical plane of the objective of the telescope, and its real image is at the other; the latter being at the focal plane of the eye-piece, the observer sees a magnified real inverted image of the corneal reflections. The doubling apparatus is, according to its nature, placed either between the components of the objective, or in the convergent light from the latter.

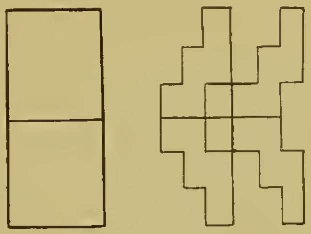


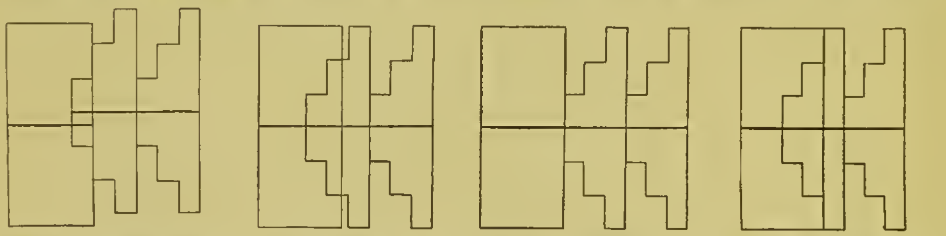
Fig. 98.

Of the movable mire type of ophthalmometers a brief description of one of the latest patterns, the Ettles-Curties, will show the underlying principles of this class, which also includes the Javal. The mires are carried on an arc concentric with the centre of rotation of the cornea; the one is a rectangle with a central black line across the shorter diameter, and the other is "stepped" or divided into equal spaces, also with a central line, as will be seen from Fig. 98. Both mires are translucent, and suitably illuminated from behind by glow lamps, and can be moved equally towards and away from each other on the arc. The latter is suitably scaled to indicate diopters, and fractions, of anterior corneal refractive power by means of an index on the mire. The arc is attached to the telescope, so that the two may be rotated bodily on a horizontal axis, in order to bring the mires into any desired meridian, the angle of the latter being indicated by means of a pointer moving over a translucent protractor.

Now suppose a living cornea to be examined. Having focussed the telescope, *four* images are seen, the two central ones generally being crossed, and it is upon this central pair that attention is concentrated, the outer images being ignored. The central images can then be made to touch by means of the rack actuating the mires and, if the cornea is spherical, they will remain in contact as the arc is rotated through every meridian. If, however, there is astigmatism, the distance between the images will vary, as the arc is rotated in the different meridians, on account of the variation of curvature; further, the images will be seen to have a curious eccentric sliding motion with respect to each other.

To locate a principal meridian we have only to find that direction in which the short black lines on the mires are continuous with one another, since this occurs *only when the meridian parallel to the plane of the mires is spherical.* The appearance is analagous to that seen in neutralizing, where the arms of a cross are undistorted only when they are parallel to the principal meridians of the lens.

Having therefore secured a principal meridian, we cause the images to touch as in Fig. 99, and the reading on the arc is taken; say this is 43·5 D. The angle of this principal meridian is also read off and, for the purpose of illustration, let this be 60°. The whole arc is now rotated through exactly 90°, so that the plane of the mires now lies in meridian 150°, and the images will be seen to overlap or separate according as the second meridian is, respectively, of greater or lesser curvature than the first. If they overlap at 150° the excess of power, as compared with the first meridian, can be read off directly from the number of steps, and fractions thereof, overlapping the rectangle, each step being equivalent to 1 D. Or contact can again be made by moving the mires, and the difference in the readings on the arc shows the amount of astigmatism. Thus suppose the second reading—that at 150°—is 45 D.; there is, therefore, 1·5 D. more power than at 60°, where it is 43·5 D. On the other hand, suppose the second reading to be 41·5 D.; then we know that there is a deficiency of refraction of 2 D. in meridian 150° as compared with 60°. The images at 150° are separated, but they can be brought into contact by moving the mires towards each other, and when contact is secured a reading is made. The arc is then turned back to 60° and the amount of overlapping again shows the degree of astigmatism. It is advisable to measure the astigmatism



Images overlapping and off a principal meridian.

Images overlapping but in a principal meridian.

Images in contact in first principal meridian.

Images showing 2 D. greater power in the second principal meridian.

Fig. 99.—Diagram illustrating Four Stages of a Reading taken with an Ettles-Curties Ophthalmometer.

by both the arc reading and the overlapping of the image, so that the one may confirm the other. With practice a difference of ·25 D. is easily detected and measured.

The other forms of two-mire instrument, where the mires are fixed and the doubling apparatus moved, are similarly worked, with the exception that the readings are taken from a drum or dial, and not from the mires themselves.

Movement of the doubling apparatus, however, renders the use of a single mire possible and this is to be found in the newest forms of keratometer, which are essentially one-position instruments, a secondary rotation of the mire being unnecessary. The "Sutcliffe" keratometer differs from all others, and is unique in that the doubling of the images is obtained simultaneously in the two principal meridians, the image of the single mire being triplicated; in this way, the principal meridians being located, contact is made for both and the degree of astigmatism at once obtained. In the Gowlland "New" keratometer the doubling is obtained from a prism which, by a patent device, is automatically rotated through exactly 90° to obtain contact for the second reading. The limbs of the mire are especially fine to insure exactitude in the location of the principal meridians and measurement of the astigmatism. A special attachment is supplied, whereby the prism can be rotated independently of the mire, thus enabling measurements to be taken in other than the principal meridians.

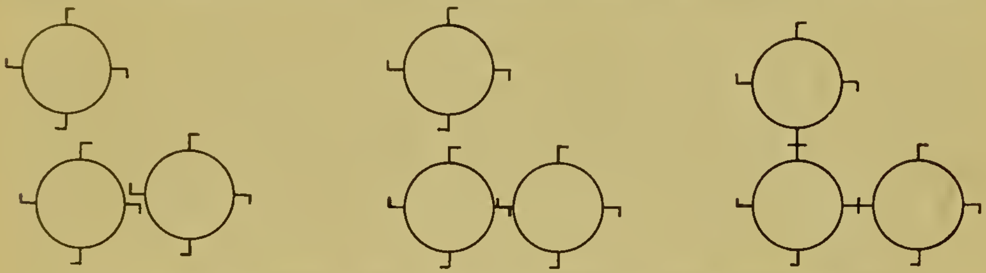


Fig. 100.—Illustrating the Appearance of the Mires of the "Sutcliffe" Keratometer.

The first diagram shows the triple images out of alignment, the second shows them in alignment, and the third with contact in both principal meridians.

For a detailed description of the many instruments, the reader should obtain the pamphlets issued by the various manufacturers.

Utility of the Ophthalmometer.—From the ophthalmometric test we obtain, in addition to the degree of corneal astigmatism, the principal meridians and actual curvature of the cornea. We also acquire a knowledge of the surface polish and errors of curvature such as irregular As. and conical cornea which otherwise are difficult to detect.

Occasional cases may be met with where apparently the maximum and minimum curvatures are not exactly 90° apart, as shown by the alignment of the mires. This is not evidence that the principal meridians, in the centre of the cornea, do not lie at right angles to each other, but rather that there is some peripheral irregularity.

The ophthalmometric determination of the principal meridians of the cornea does not usually differ much from that of the eye found subjectively, or by the retinoscope, say not more than 5° either way. The degree of total As. of the eye, although generally very nearly or exactly the same as that of the cornea, may differ from the latter very considerably, owing to the astigmatic static or dynamic curvature of the crystalline, or on account of its obliquity to the optic axis. In general, however, it may be said that degrees of As. less than ·5 D., and over 2 D., are more likely not to agree, than values between these figures. The final determination of the power of the corrective lenses can only be obtained by the subjective test with the astigmatic chart and types; consequently the ophthalmometer must be employed, not to corroborate the subjective test, but as a preliminary to it. The cyl. given to correct As., found by the ophthalmometer, should be concave with the axis in the meridian of lowest refraction, or whose power is in that of the greatest refraction. Apart from the changes due to the crystalline, the cyl., if of low power, will correct the astigmatism provided the latter is not associated with high H. or M. In high degrees of As., especially if there is medium to high H. or M., it will be found that considerable modification is required subjectively, if the cyl. is first placed before the eye and the general spherical error worked out afterwards. This is due to effectivity (*q.v.*).

It is usual to liken the general shape of the cornea to that of an ellipsoid of revolution, but the true form is only approximately ellipsoidal. It has been suggested that a better analogy is that of a hyperboloid of revolution, whose apex has been replaced by a spherical cap about 3 or 4 mm. in diameter. Whatever the true shape, however, the curvature rapidly diminishes beyond a certain point, so that it is important in ophthalmometry to insure that the images are formed symmetrically with respect to the visual axis. If the observed eye deviates the images may lie considerably to one side or the other and they will be seen very distorted or drawn out. In an astigmatic cornea we may say that the surface is only truly toroidal over an area not exceeding some 3 to 4 mm.

The meridians oblique to the principal meridians are, of course, elliptical in section, but over a moderate area they do not depart greatly from sphericity—at any rate not to an extent sufficient to render the measurement of their power valueless, because readings in actual cases taken by the author, show results agreeing perfectly with the theoretical powers indicated by calculation.

Artificial Astigmatism.—The standard reflecting sphere, supplied with most ophthalmometers, can be used with ordinary cyl. lenses to produce artificial astigmatism for practice purposes. An artificial truly astigmatic cornea is very convenient, but it is limited to one condition only, so that the beginner has no means of checking his readings, or of obtaining any variation in the amount of astigmatism. Now a convex cyl., with its curved surface in contact with the sphere, *reduces* the negative reflecting power across the axis, while a concave cyl., similarly placed, *increases* it. In both cases the power parallel to the axis is unchanged.

Let R be the reflecting power of the sphere, D the refracting power (on an index of 1·3375), and P the power of the cyl. We may ignore the distance of the mires from the sphere as not affecting the calculation to any appreciable extent. Suppose the cyl. to be concave. Then the combined *reflecting* power of sphere and cyl. is R + 2 P. The *refracting* power across the axis, as compared with the meridian parallel to the axis, is therefore—

$$\frac{D(R + 2\ P)}{R}$$

so that the artificial astigmatism As. produced is—

$$\text{As.} = \frac{D(R + 2\ P)}{R} - D = \frac{2\ PD}{R}$$

Now the focal length of a mirror of radius 7·5 mm. is 3·75 mm., so that the reflecting power of a standard sphere of cornea is 266 D., whereas its refracting power is 45 D. Thus the ratio of the reflecting to the refracting power is approx. 6 : 1.

Now $D = 45$ and $R = 266$

$$\therefore \quad \text{As.} = \frac{90\ P}{266} = \frac{P}{3} \text{ very nearly.}$$

Therefore we have the rule that the *artificial astigmatism produced is approximately one-third the power of the cyl. causing it.* Thus if the cyl. be 3 D., As. = 1 D.; if P = 6 D., As. = 2 D. and so on.

It should be noted that a convex cyl. causes an increase in the size of image across the axis, and a concave cyl. a reduction, so that the former produces a hypermetropic, and the latter a myopic effect.

For the above calculation to hold good, the curved surface of the cyl. must be in contact with the cornea. Again, although the thickness of the glass in the axis causes a slight alteration in the clearness of the image, the ophthalmometer must not be refocussed between the first and second positions.

CHAPTER XVIII

RETINOSCOPY

RETINOSCOPY may be defined as the measurement of ocular refraction by means of the real or apparent movements of the fundus reflex. It is based on the laws governing the conjugate foci of simple lenses since the eye itself, although actually a complicated system, is equivalent to a single lens of some 20 mm. focal length.

From first principles, we know that the real image formed by a single lens is on the opposite side to the object, whereas a virtual image is always on the same side. It follows, therefore, that any movement of an object will cause its real image to be displaced in an *opposite* direction, just as though both object and image were at opposite ends of a rigid bar pivoted on a point corresponding to the optical centre of the lens. On the other hand, the movement of a virtual image corresponds to that of the object; here—to employ the same simile—both image and object are situated on the rigid bar on the same side as the pivot, *i.e.* the optical centre. On these simple laws the whole theory of retinoscopy depends and, to anyone possessed of a knowledge of elementary optics, a mastery of the theory of the subject should present no difficulties. However, the variety of different possible cases is generally confusing to the beginner, while the practical application of retinoscopy calls for practice.

Ordinarily the pupil of the eye is seen black because an observer is never in a position to receive the light from the retinal image of a source sufficiently bright to enable the fundus to be seen. In other words, the light from the observer's face is too feeble to give the necessary illumination to the observed fundus, and it is useless to attempt to intercept the light returning from the image of a bright source such as a lamp because, the source of light and the fundus image being conjugate foci, any attempt to view the latter results in the occlusion of the former by the head of the would-be observer. To overcome this difficulty, the observer's eye must be in line with the direction of the entering light, and for this purpose a mirror having a central perforation is employed. Light from some extraneous source is received by the mirror and reflected into the observed eye, where it comes to a more or less well-defined focus on the retina. The latter is, however, transparent (in health), so that the returning light is that diffused by the choroid, the vessels and pigment of which give the reflex its characteristic reddish colour. This the observer can readily perceive since his eye can now receive the returning light through the mirror aperture which is on, or near, the axis of the incident pencil. In some cases, however, a glimpse of the reflex may be obtained without the aid of the perforated mirror. This occurs when the pupil is abnormally large in relation to the length of globe, so that the reflex may sometimes be seen in high H. with dilated pupils owing to the divergence of the emergent beam, or in high M. where the light diverges rapidly from the P. R.

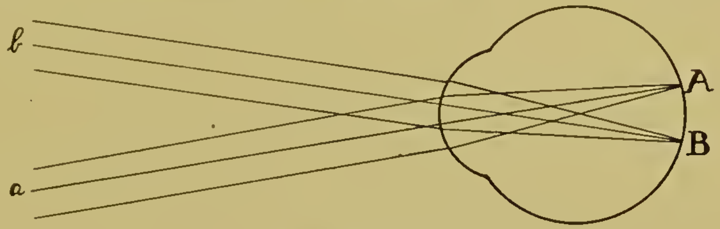


FIG. 101.

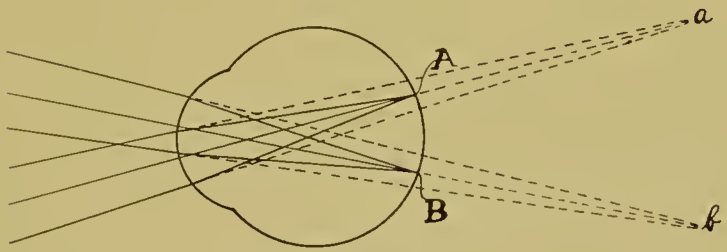


FIG. 102.

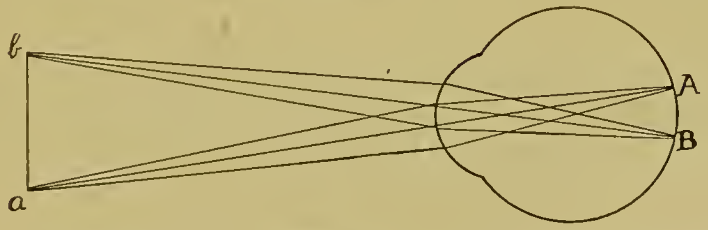


FIG. 103.

SHOWING THE EMERGENT LIGHT IN EM., H., AND M., FROM A PORTION *AB* OF THE FUNDUS.

a b is the far point in each case.

In Em. (Fig. 101) the light emerges from the eye in parallel beams, the fundus being at the posterior focal distance. In H. (Fig. 102) the fundus is within the posterior focus and therefore the emerging pencils are divergent as if from behind the eye, while in M. (Fig. 103) the fundus is beyond the focus, so that light returning into air is convergent. The point towards which the emergent light converges in myopia, or from which it appears to diverge in hypermetropia, is the conjugate focus of the retina, and is the far point of the eye when accommodation is at rest. The P. R. in emmetropia is at ∞.

In retinoscopy—and in ophthalmoscopy—the function of the mirror is solely to supply the requisite illumination; its nature, *i.e.* whether it is convex, concave or plane, is immaterial, but the intensity of the beam and therefore the brightness of the fundus reflex depends to a great extent on the nature, focal length and aperture of mirror. In addition, the rapidity of the movements of the reflex depends directly upon the degree of divergence or convergence with which the light leaves the mirror.

Suppose light from some adjacent source be reflected into an observed eye by means of a plane mirror. An observer looking through the aperture will see the pupil suffused with a red glow which, on slowly rotating the mirror, will move either in the same or opposite direction to that of the mirror, depending upon the refraction of the eye and position of observer. This reflex is either the real or virtual image of the illuminated fundus; it is real when the observer is beyond the far point of the eyes and virtual when he is within it. Or, more specifically, the image of the fundus of an Em. eye is virtual, it being formed by parallel rays; it is similarly virtual in H., and also in M. provided the observer is within the far point. In the last case the rays are convergent to a point behind the observer's eye. If the observer is beyond the far point of a myope, the reflex is then real since the light has formed a real image of the fundus between the observer and the observed eye. Although we are said to see the fundus reflex, yet it is very rare that any details are noticed, since the magnification is too high and the field of view too small. Also, although theoretically the image of the fundus formed by the emergent light is at the far point, the reflex always appears merely as a reddish illumination of the pupil.

When, therefore, the mirror is rotated, the reflex appears also to move across the pupil, but as a matter of fact it is the boundary between the illuminated and non-illuminated portions of the fundus that is noticed—referred to generally as the *shadow*. The direction of the shadow movement, with or against the rotation of the mirror, depends upon the refraction of the eye, the nature of the mirror and the position of observer.

Plane Mirror.

Emmetropia.—For convenience let the observer be at 1 m. from the observed eye. Let O (Fig. 104) be the observed eye, S any convenient source of light and M the plane mirror behind which is the observer. Light is reflected from M such that it appears to diverge from the virtual image S', the light from which comes to an approximate focus F on the retina. To avoid confusion, rays entering the eye are not shown. The diffused light which returns along its original path FN (N being the nodal point) is rendered parallel as if from the reflex image R at ∞ which, as before pointed out, is seen merely as a red glow in the pupil. If, now, the mirror be tilted to the left to M' the virtual image S'—which is the actual source of illumination—moves in the opposite direction, *i.e.* towards S'', while the retinal image F and the reflex R shift respectively to F' and R'. If, therefore, the rotation of the mirror be sufficient, the shadow following the reflex R will appear to move *in the same direction as the mirror.*

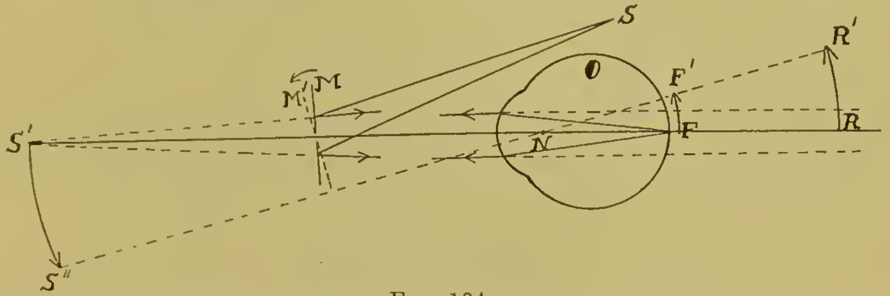


FIG. 104.

Hypermetropia.—Precisely similar arguments apply in any degrees of H., the only difference being that the emerging rays are divergent and the reflex R is now within ∞ at some near distance behind the retina (Fig. 105). In consequence the movement of the shadow is slower than in Em. and the illumination duller on account of the divergence of the emerging rays, only a small proportion of which can enter the observer's eye. Thus *in* H. *of any degree the shadow apparently moves with the plane mirror.*

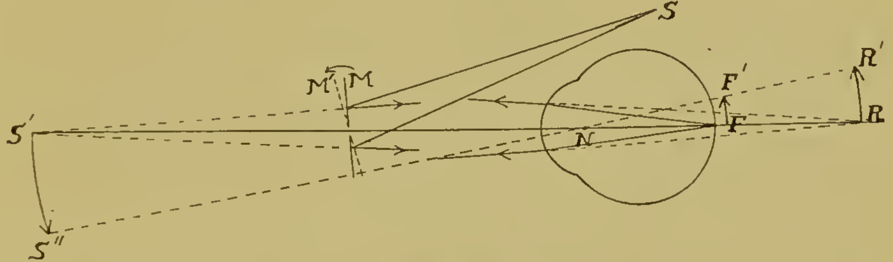


FIG. 105.

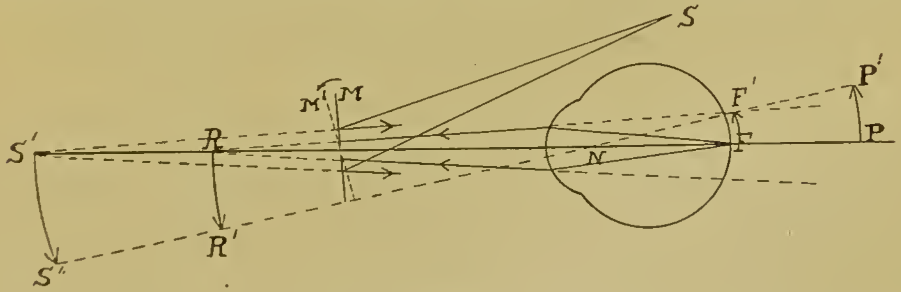


FIG. 106.

Myopia under 1 D.—Suppose there be M. (Fig. 106) of such a degree that the observer is within the far point R, that is, since we have taken

1 metre as the point of observation, the M. under consideration is less than 1 D. In this case the emergent light is convergent towards a point R *behind the observer* and, therefore, not having crossed, *it is referred back to a point P behind the retina as in* Em. *and* H. so that the apparent movements P to P' of the shadow are also similar to those in Em. and H. The speed of the reflex and its intensity are, however, greater than in other conditions since the emergent light is convergent. Therefore, *in* M. *under* 1 D.—*the operator being at* 1 m.—*the shadow moves in the same direction as the mirror.*

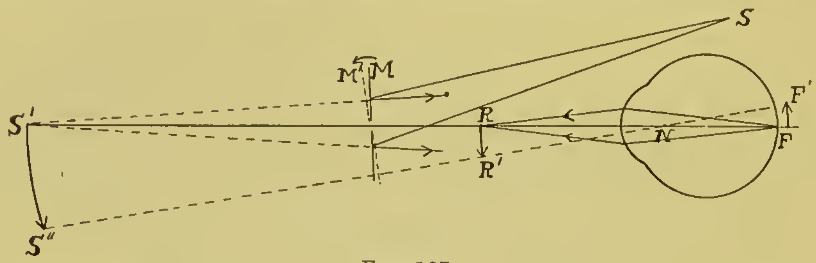


FIG. 107.

Myopia over 1 D.—If the M. exceeds 1 D. the far point (Fig. 107) is within 1 m. so that light, diverging from the fundus, now crosses in the air at a point R in front of the observer. When S' moves to S'', then F moves to F', but R the reflex is real and therefore moves to R' in an opposite direction to the fundus illumination; so that *in* M. *over* 1 D. *the shadow appears to move in the opposite direction to the plane mirror.*

Myopia 1 D.—We have seen that, in M. under 1 D., the shadow moves with, and if over 1 D. against the plane mirror; therefore there must be some intermediate degree of M. wherein the shadow moves neither *with* nor *against*,

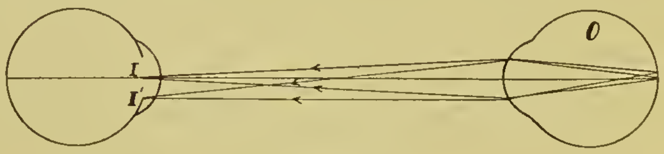


FIG. 108.

and this occurs *when the distance of the far point is equal to the distance of the observer.* When the latter is at 1 m. the degree of M. giving no movement of the shadow is 1 D.; if the observer were at any other distance the amount of M. would vary accordingly. Thus for the *point of reversal, i.e.* the point of no shadow movement, to be at 2 m., there must be ·5 D. M.; at 50 cm., 2 D. M., and so on. The reason for the apparent stoppage of all shadow movements when the P. R. of the eye is coincident with the cornea of observer will be seen from the next diagram. In Fig. 108 let O be the observed eye from which light emerges to focus at I in the pupillary aperture of the observer. Then suppose a small rotation of the mirror (not shown in the sketch) be made sufficient to transfer the far point *I* to the edge of the pupil *I′*; the reflex will not alter in appearance since the divergence of the light within the observer's eye will remain the same as when the beam converged to the position *I*; but if the slightest extra rotation of the mirror now be made *I′* will focus on the iris itself and therefore *all* the light entering the observer's eye will be suddenly cut off. To the observer, therefore, the reflex suddenly comes and goes as the mirror is rotated, and is not followed by any definite shadow. In Fig. 108 the refraction which the pencils undergo at the observer's cornea is neglected for simplicity. When, therefore, all movement of the shadow ceases, we know that *the eye under observation is myopic to an extent represented by the distance of the observer*, this being M. 1 D. for a distance of 1 metre.

For any other degree of M. the observer must move backwards or forwards until he picks up the point of reversal. This method is, however, uncertain in low M. and altogether useless for H. since in the latter the point of reversal is virtual and negative. It is more convenient, then, to remain a fixed distance of 1 m. from the subject and, by putting up the necessary lenses, secure the point of reversal by making the eye artificially M. 1 D. Then the correcting lenses are those producing the point of reversal, *with the addition of* −1 D. sph. to allow for the artificial M. caused. Thus if the shadow is neutralized with +4 D., the correcting lens is $+4-1=+3$ D. If it is −4 D. the correction is $-4-1=-5$ D. and so on. Of course the position of the observer can be altered at will, and sometimes it is more convenient to work at a shorter or a greater distance than 1 m. Whatever the distance, however, the procedure is the same, but the final added lens *must always be that concave whose focal length equals the distance of the mirror from the eye.* Theoretically it is possible to work at so great a distance that the lenses found to give the point of reversal would also be the correction, no additional negative spherical being required. But practically this is not at all easy, as it is difficult to see the reflex at any great distance.

Concave Mirror.

If, instead of a plane, a concave mirror be used, all the movements seen with the former are exactly reversed. This is due to the fact that, with the concave mirror, the actual source of illumination is the real image of the stationary source, and this moves in the same direction as the mirror, while, with the plano, the actual source is virtual and has an opposite movement to that of the mirror. Thus the various shadow movements are all seen reversed to those of a plane mirror provided the conjugate focal distance of the lamp, formed by the Cc. mirror, *is less than the distance of the observer to the observed eye.* If the conjugate is greater than this, the shadows move as with a plane mirror, but the illumination is very much superior. This principle is applied in the Orthops retinoscope, which consists of a long focus concave such that the crossing point of the reflected light would be behind the subject's head.

The action of an *ordinary* concave mirror, which is usually of 10-inch focal length, in retinoscopy will be seen from Fig. 109 which represents a case of H. As before S is the source of light, M the mirror and O the observed eye. Light diverges from S to the mirror and is converged to the real conjugate image S', from which the light again diverges to illuminate the fundus at F. The rays diffused by the fundus emerge into the air as if divergent from the virtual far point R. If the mirror be rotated to M', to the left, S' also moves to the left towards S'', F moves to the right to F', and R also to the right. R being virtual, the observer behind M also sees the reflex as moving towards the right *or in an opposite direction to M.* Similarly it can be shown that, for any other refractive condition, the shadow movements are reversed to those of the plane mirror on account of S' being real instead of virtual.

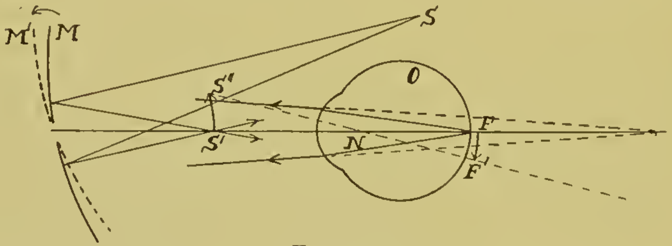


Fig. 109.

To summarize, therefore—if the observer be at 1 metre and the mirror plane or long-focus concave—

In H. of any degree	The movements of the reflex and shadow are *with* the rotation of the mirror.
In Em.	
In M. under 1 D.	
In M. 1 D.	No movement.
In M. over 1 D.	The movements are *against* the rotation of the mirror.

With the concave mirror, the observer being at 1 metre—

In H. of any degree	The movements of the shadow are *against* those of the mirror.
In Em.	
In M. under 1 D.	
In M. 1 D.	There is no movement.
In M. over 1 D.	The movements are *with* those of the mirror.

Intensity of Reflex.—Thus it will be seen that the reflex is quite independent of the nature of the entering light since the function of the latter is merely to illuminate the fundus. *It is the light diffused by the fundus that gives rise to the reflex and shadow,* so that the nature or focal length of the mirror employed is quite immaterial except from the standpoint of illumination. A convex mirror could be used and its action would be the same as the plane, but the intensity of the entering light would be too low to give anything but a feeble reflex. Generally there is not much to choose between the intensity given by the plane and ordinary 10″ Cc. of equal aperture at 1 m. Within this distance the Cc. gives the brighter reflex, and beyond it the plano. The question of aperture is, however, of much greater importance in this connection in the case of the concave, and therefore the latter should be as large as possible in order to secure the maximum illumination. The Orthops, for its size, gives the brightest illumination, which is sometimes too intense. The brightness of the reflex also depends upon the degree of Am. in the eye under observation. It is brightest at the point of reversal because, in this position, the whole of the light diverging from any fundus point is converged to the pupillary aperture of the observer. The higher the Am. the more feeble will be the reflex, for two reasons: (1) In H. and M. the slightly divergent light from the plane mirror is spread over a larger area of the fundus than if the image were perfectly sharp thereon. (2) The emergent cones of light are divergent in H. and M. over 1 D. when they reach the observer's eye, this divergence increasing with the Am., so that only a small proportion of the light constitutes the reflex. In some instances of very high M. no reflex at all can be seen with the plane mirror until a fairly strong concave lens is put up to reduce the extreme convergence of the light towards the P. R. With the concave mirror, the illumination is still more feeble in H. since the image on the observed fundus is more out of focus than with the plano. On the other hand a concave mirror is an advantage in medium and high M., because the focus of the mirror is more nearly at the P. R. of the eye, so that the image on the fundus may be comparatively sharp and the resultant reflex bright. Thus in M. it is advantageous to use the concave, while in H. the plane or long focus concave (the Orthops) gives the better result. The latter also gives a better result when the Am. is very high and the reflex feeble. If, therefore, at the first glance the reflex is very dull a change of mirror may result in an increase in brightness and definition.

Speed of Reflex.—The *speed* of the reflex, *i.e.* the relative movement of the shadow for a given rotation of the mirror, depends both on the focal length of mirror and degree of Am. We may ignore the plane mirror in this case, since it must always give the same relative result unless the distance of lamp be altered. With the concave, the nearer the focus to the observed eye the quicker will be the shadow, since the source, for the same speed of rotation of the mirror, takes less time to cross than the image projected from a mirror of shorter focal length. Presuming that the use of a convex mirror were practicable, the reflex would be slowest of all in this case; it is most rapid with the Orthops, and therefore the latter is useful in the first stages of a test in high Am.

Am. affects also the speed of the shadow in that the higher the error the more sluggish is the movement. The maximum speed is, of course, attained in M. 1 D., the point of reversal. As we have seen, the higher the Am., the nearer is the far point (or image of the fundus) to the observed eye, and therefore the slower is the reflex, for any given movement of the fundus illumination. Although the reflex is dull in high Am., yet the sluggish movement is a considerable advantage, as the shadow can be followed with great ease; as the lenses put up approach nearer and nearer to the correction, so does the shadow quicken and its observation become more difficult. When very near the point of reversal it is often very difficult to say which of two or three lenses is the correct one, and in such cases it is best to note those giving opposite movements; the mean of these will be that giving the point of reversal. Thus, if + 3·5 D. gives a decidedly *with* movement and a + 4·0 D. an equally marked *against* movement the reversing lens is + 3·75 D.

Definition of Reflex.—Similarly the *sharpness* of the boundary between reflex and shadow depends upon the Am. and also, to a lesser degree, upon the nature of the mirror used. The more perfect the fundus illumination, *i.e.* retinal image of source, the sharper and cleaner will be the shadow, but the definition of the retinal image depends obviously on both Am. and type of mirror. Thus the nearer the source of illumination to the P. R. of the eye, the clearer will be the retinal image, so that in Em. a plane mirror or a very weak concave giving parallel reflected light will produce the sharpest reflex. Similarly in H. a long focus concave and in myopia a short focus concave will, before any lenses are put up, give the clearest reflex. Of course it must not be forgotten that the lenses used to get the point of reversal may impair the definition of the shadow, and for this reason it is frequently hard to say with what exact power the reversal is obtained.

In H. and M., provided the source of light is circular, the reflex and shadow take the form of a crescent whose curvature is greater as the Am. is higher, because then the reflex image is small. With lower degrees of error the shadow is less curved so that, in low Am. when near the point of reversal, the shadow may appear quite straight owing to the great size of the reflex image, only a small portion of which is seen through (in H.), or projected on to (in M.), the pupil of the observed eye. On the other hand, sometimes, in high H. or M., the whole of the reflex may be seen as an ill-defined circle of illumination, which enlarges as the trial lenses are successively put up.

In As. we may say that there are two far points corresponding to the principal powers of the eye. Thus light diverging from some point on the fundus is brought to a focus outside the eye in the shape of two focal lines, both of which may be virtual, or real, or one real and the other virtual. Both are real in compound M. As., both virtual in compound H. As., and one real and one virtual in mixed As. The form of the fundus illumination of an astigmatic eye will, in general, be elliptical but, unless in very high errors, the difference in the powers of the principal meridians is so slight that the reflex of a round source will also be practically circular and, therefore, the general play of the shadow, except in one special instance, is similar to that in ordinary H. and M.

If the principal meridians are known, and the mirror rotated first parallel to the one and then to the other, a difference in speed and sometimes in direction will be noticed between the two shadows. This is due, of course, to the different degrees of error at right angles to each other, and the movements of the shadow in the principal meridians conforms to the ordinary rules given above for simple H. and M. Thus in compound H. As. with the maximum power vertical, the plane mirror will produce *with* shadows in both the horizontal and vertical, but the movement in the horizontal will be slower than that in the vertical. In a similar case of M. As. the slower *against* movement would be in the vertical and the quicker in the horizontal. If the movement of the mirror be oblique to the principal meridians, the reflex and shadow may follow the mirror, but generally the *apparent* movement of the shadow takes place only along the principal meridians, no matter in what meridian the mirror may be rotated. This occurs in the *band* appearance of the reflex.

In compound M. As. both lines are real and formed in the air. Now if the observer's eye should happen to coincide with either line, the reflex will take the form of a more or less well-defined band parallel to one of the principal meridians. The formation of the band is easily understood. Since the eye is coincident with a focal line, it is also at the point of reversal of one of the principal meridians, and therefore in one direction the reflex extends right across the pupil to suddenly appear and disappear as the mirror is rotated. At right angles to this meridian, however, the light is either crossed or uncrossed, and therefore has the usual with or against movement as the mirror is rotated. For instance, suppose a case of compound M. As. where there is excess of 2 D. in the vertical and 3 D. in the horizontal. Light diverging from a point on the fundus focusses at two lines at 50 and 33 cm. respectively, the one at 50 cm. being horizontal and that at 33 cm. vertical. If now the observer commence with the plane mirror at 1 m. he will get nearly equal against movement of the shadow in all meridians, and the reflex will be approximately circular. On approaching the observed eye the shadow will be quicker and will show a tendency to confine its movement to the horizontal and vertical planes. At 50 cm. the reflex will be seen to extend right across the pupil vertically, and in this meridian no movement will be seen, since 50 cm. is the point of reversal for that meridian. In the horizontal the movement is still against, the combination of the two giving the vertical bandlike appearance. From 50 cm. to 33 cm. the observer will see a very quick vertical *with* and a horizontal *against* movement, the edges of the reflex tending now to broaden out in the horizontal. When 33 cm. is reached, there will now be a horizontal band showing no movement horizontally but *with* vertically. Within 33 cm. the reflex will return to its approximately spherical shape, the movement in all meridians being *with* the plane mirror.

At first sight, therefore, it is often impossible, except for a practised observer, to detect the presence of As. This is especially so in H. and in low differences, because the shadow has apparently the same outline and degree of movement in all meridians. It is only when, by the addition of + lenses, both focal lines are made real that the band appearance can be attained, and since the correction of As. is rendered much more easy and exact from observation of the band, it is as well if the beginner concentrated his attention on securing this position in all cases. In practice it is not usual for the observer to change position to secure the point of reversal, but rather to do this by means of + or – lenses to bring the first line to his eye. The other, in H., will then be behind his head and can be brought forward by means of that + cyl. which, when placed parallel to the band, gives the point of reversal in the opposite meridian. In M. the more distant focal line is at the eye of the observer, and therefore a concave cyl., similarly placed parallel to the band, must be employed to give also reversal in the opposite meridian.

The beginner must not, of course, expect to find a well-defined band movement in every instance—a well-marked case is the exception rather than the rule. Aberration chiefly mitigates against the formation of sharp or well-defined shadows, but matters may often be improved by using a small source of light.

Equipment.—The essential apparatus for retinoscopy comprises only a test case, trial frame and mirror. For preference the frame should be of the drop-cell type in order to facilitate the changing of lenses; the springs on the better class of frame are apt to be troublesome, especially as the test is carried out practically in darkness. Both kinds of mirror should be at hand as it is often necessary to change from one to the other, and it is convenient to have some distinction between them, such as a difference in size, or length of handle. The plano should be about the same diameter as an ordinary trial lens, *i.e.* 1½ inches, as this very conveniently fits into the angle formed by the nose and frontal bone of the face, thus enabling a steady grip to be maintained on the mirror. If the latter be large it is not quite so easily handled, but optically it is superior and is generally employed by the leading ophthalmologists. A small mirror should be avoided as it has a tendency to cut off its virtual image too quickly, whereby a good shadow is apt to be ill-defined and indefinite when passing out of the pupillary aperture. Similar remarks also apply to the concave. In neither mirror should the sight-hole be larger than is absolutely necessary, and generally a diameter of 2 to 3 mm. will be found to be ample. A large sight-hole casts an annoying shadow at the centre of the reflex, especially if a small source is in use, and for that reason should be avoided. An aperture too small is apt to give rise to a "ghost," especially if the mirror is perforated. For beginners a long-handled mirror will be found much easier to manipulate than the short folding type.

As regards the room, this should be as dark as possible in order to induce relaxation of Ac. and dilatation of the pupils. Some little light is, however, necessary in order to handle the lenses and therefore, for preference, the test case should be placed under the lamp, so that, if necessary, the light can be reflected from the retinoscope mirror into the case when a lens is required. The same device should be made use of in determining the axis on the frame—that is, light from the mirror may be directed on to the frame when adjusting cyls., etc. It is a mistake to have the room absolutely dark; rather there should be sufficient light to show up vaguely the opposite wall, so that the subject may have somewhere to direct his gaze. Many prefer a special fixation point, *e.g.* a small electric light in a dense blue globe, which serves to keep the subject's eyes steady and away from the mirror. Such an arrangement tends rather to relax the accommodation and dilate the pupils, especially if the fixation point is blue or violet, which colour requires the minimum Ac. to focus on the retina.

The retinoscopic source should, for preference, be electric, as it can then be more completely enclosed. If electricity is not available, gas, or an ordinary oil lamp, may be employed providing it is fairly well screened; for this purpose tall cylindrical asbestos chimneys are necessary, and if used with an Argand burner will give good results. The bracket supporting the lamp should be adjustable as to height, projection and lateral swing, and should be so placed that, when in its mean position, it projects just above the client's head. The aperture of the source of light should be as small as possible, but as sometimes a greater amount of illumination is required than at others, it should be adjustable. The iris form of diaphragm is very convenient and should have minimum and maximum openings of about 5 mm. and 25 mm., and the whole shade should be easily detachable to expose the source itself, which is sometimes to be preferred in ophthalmoscopy and general external examinations of the eyes.

General Routine.—Having seated the subject, the observer should adjust the lamp above and a little to one side of the head on the same side as the eye to be tested. Having put on the trial frame and occluded the other eye, the client's gaze should be directed to the opposite side of the room or fixation point; the observer then takes up his position at about 1 m. distance and directs the beam of light somewhere in the direction of the optic axis, but as near to the visual axis as possible without bringing the mirror into the subject's line of vision. At first some little difficulty may be experienced in getting the reflected light on to the eye at all, and therefore both eyes should be kept open so that the disc of illumination from the mirror, as it travels over the subject's face or clothes, may be followed. Having secured the reflex, a general indication of the nature of the defect should be obtained by rotating the mirror in several meridians and the point of reversal approximately arrived at by means of sphericals. This preliminary test may be done rapidly without any special attention being paid to the finer movements of the shadow; it is only when the general point of reversal is obtained that the real test commences.

As in ordinary subjective testing, As. is always assumed to be present until it is proved to be absent. When nearing reversal, therefore, the characteristic astigmatic band should be looked for, and apparent movements in one particular direction will locate this as a principal meridian. Having secured exact reversal for one meridian, that of the other is obtained with the necessary cylindrical axis parallel to the band. Then the lenses producing complete reversal, with the addition of – 1 D. sph., is the required correction. Of course, should reversal be obtained simultaneously in all meridians, astigmatism is presumed to be absent. In practice it is better to obtain a decided reversal of the movement rather than an exact neutralization. The latter is sometimes difficult to secure on account of aberration, and by reversing the shadow movement we obtain a clearer knowledge of the refractive condition.

Two or three numerical illustrations will perhaps render the general routine somewhat clearer. Thus suppose an eye requires as its correction + 3·0 S. ○ + 2·0 C. Ax. 45. What will be the general appearance of the reflex and shadow as the correction is arrived at?

Assuming the plane mirror to be employed, a preliminary examination will show the reflex to be approximately circular, the shadow crescent-shaped and moving rather sluggishly with the mirror; the illumination will also be dull. Possibly a difference in movement in the various meridians may be detected at this stage, but no attempt should be made to correct it. Convex sphericals are now put up, causing the reflex to brighten and quicken until with, say, + 3 D. in position, the shadow will show a tendency to confine itself to the oblique meridians 45° and 135°, and immediately this is noticed the mirror rotations should henceforth be also confined to those meridians. At this period also a more or less well-defined band may have made its appearance, which is still further accentuated with a + 4 D. in the frame. Complete reversal will now be found in meridian 45°, the shadow at right angles still moving with the mirror. Attention is now concentrated on the movement in meridian 135°, this being neuralized with a + 2 D. cyl. ax. 45°. The observer should now approach slightly to see whether *with* movement again reappears *equally in the principal meridians;* if movement is apparently equal in all directions the cyl. may be taken as correct; on the other hand a slight modification may be necessary. The lenses now in the frame are + 4·0 S. ○ + 2·0 C. Ax. 45°, and therefore the correction found by the addition of the necessary – 1 D. is + 3·0 S. ○ + 2·0 C. Ax. 45°.

Again, suppose a case of 3 D. simple M. As. with the maximum meridian at 100°; concave mirror in use. The preliminary reflex will be approximately circular but, on rotating the mirror in different meridians, a contrariety of movement will be noticed approximately in the horizontal and vertical—the latter *with* and the former *against*. On a more careful examination, however, the principal meridians will be seen to lie just off the vertical and horizontal, but the exact determination of the axis is left until reversal in one meridian is obtained. The horizontal showing a condition less than 1 D. M., is neutralized with a + lens, the exact strength necessary being + 1 D. A well-marked band should now be observable lying in meridian 10° and moving sluggishly *with* in meridian 100°. This is arrested by means of a – 3·0 cyl. axis 10° so that the total reversal correction is + 1·0 S. ○ – 3·0 C. Ax. 10° which, with the necessary addition of – 1 D. S., gives as the final correction – 3·0 cyl. ax. 10°. In clinical work it is the general practice to secure reversal separately in the principal meridians by means of sphs. only, instead of leaving the first sph. in the frame and making up the difference with a cyl. Either method may, however, be employed.

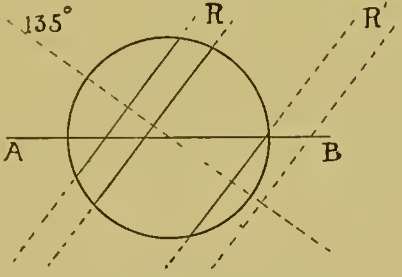


FIG. 110.

In astigmatism, when near the point of reversal, we have said that the shadow movement is apparently confined to the principal meridians. This, however, is an optical illusion due to the shape of the reflex itself. It is most noticeable in the band reflex, which has a length limited only by the aperture of the mirror in use. However the latter be tilted, the reflex and shadow always actually move in a direction parallel to that of the mirror, but the apparent movement is always parallel to a principal meridian. This is better illustrated by means of a sketch. Let Fig. 110 represent a case of oblique astigmatism such that 135° is a principal meridian. Let *R* be the band, only a portion of which is visible through the pupillary aperture. If now the mirror be rotated so that the reflex moves to the right to *R′*, the *apparent* movement will be in meridian 135°, although the reflex moves along *AB*. This resembles the effect of moving an oblique cyl.

Aberrations.—Hitherto we have assumed the reflex and shadow to be distinct and of clean outline, subject only to simple direct and easily observed changes of position. In practice, unfortunately, it is not infrequent to find just the reverse; the shadow is badly defined, has apparently no regular action, and the reflex itself broken and variable. These troubles may be due to various causes, the chief of which we propose to set out briefly in detail.

Spherical Aberration.—This is common to the great majority of eyes, but is usually too slight to cause any inconvenience to retinoscopy. It is an unequal refractive power in the various zones of the dioptric system as a whole, and is generally *positive*, *i.e.* the more peripheral regions have a higher power as compared with the centre so that, although light may issue, say, parallel immediately round the visual axis, it is convergent from the outer zones. If the opposite occurs, which is sometimes the case, the peripheral light is relatively less refracted than the central, and the aberration is then said to be *negative*. The effect of spherical aberration in retinoscopy is sometimes very marked, especially when the pupils are dilated to any extent, as under atropine. It is characterized by a ring of light at the border of the pupil, separated by a darkish space from the central reflex, the two sometimes having opposite movements, when the observer is favourably situated. In other words there is a different point of reversal for the periphery and for the centre, and the former may lie within or beyond the latter, depending on whether the aberration is positive or negative. Spherical aberration is rarely seen in undilated pupils but, whenever present, the attention should be concentrated on the central light area only.

Irregular Astigmatism is generally easily recognized under the retinoscope. The reflex is more or less broken, and no definite shadow can be seen at all when anywhere near the point of reversal. If the irregularity is accompanied by any high degree of ametropia the preliminary shadows may be fairly distinct, but as the successive lenses are put up the shadow soon loses all definite form, rendering anything but an approximate correction impossible.

Conical Cornea is a variety of irregular astigmatism wherein, owing to a weakening of the tissue, the cornea bulges forward in the shape of a cone which may, or may not, have its apex at the anterior pole. The immediate result is a condition of high myopia in the region of the apex, the refraction diminishing towards the base, where the M. may entirely disappear and be replaced by H. We may, therefore, under the retinoscope get opposite movements for the centre and for the periphery, but generally both are characteristic of M. The difference, however, at the centre and periphery is such that, while the outer portions of the shadow move comparatively quickly, the central part is extremely sluggish and may almost appear stationary. This gives rise to the curious appearance of the reflex, which has a swirling motion around a certain point, this point being the apex of the cone. The greater the deformity the more marked is the shape of the reflex but, in the initial stages of the disease, the swirl of the reflex is so slight that it may be mistaken for the effect of ordinary spherical aberration, or may escape notice altogether.

Scissors Movement.—This may be taken as a variety of irregular astigmatism, although the cause may not be any actual irregularity of the individual refracting surfaces. In appearance the shadow is split into two portions which, as the mirror is rotated, advance from opposite sides of the pupil to meet and merge into one another, giving the effect of closing the blades of a pair of scissors. On rotating the mirror in the opposite direction, the blades apparently open again and disappear at opposite sides of the pupil. Some uncertainty exists as to the actual cause of this phenomenon, but it is generally ascribed to *coma*, due to the obliquity of one or more surfaces of the dioptric media to the path of the incident light. This theory is apparently confirmed by the fact that, in an eye having a normal reflex for direct light, the scissors movement may be obtained by directing the beam very obliquely to the optic axis. Again, a tilted spherical in front can generally be made to produce a like effect.

In any eye suffering from a considerable degree of irregularity or aberration, the application of retinoscopy with success is difficult, if not impossible. In many cases, however, a considerable improvement in the action of the shadow may be obtained by the observer shifting his position from one side to the other in order to utilize the areas of least error.

Advantages of Retinoscopy.—The principal value of retinoscopy lies, of course, in the fact that it is an *objective* method of estimating the refraction—that is, the observer need only rely on his own deductions and is quite independent of the subject. It is, therefore, valuable in the case of young children, illiterates, mutes, etc., and generally those whose answers are insufficient or unreliable in the ordinary subjective test. In fact anything that renders the operator independent of the subject must be of value, and for that reason alone retinoscopy it well worth the trouble taken to master it.

Since the test is carried out in almost complete darkness, there is generally a much greater relaxation of accommodation than in ordinary circumstances. This has been thought to be partly due to the fact that in the dark nothing is distinctly seen, so that Ac. naturally relaxes, and partly to the dilatation of the pupil, the existence of a sympathetic action between the sphincter iridis and ciliary being recognized. Such a relaxation, therefore, is valuable in all cases of ametropia, but most particularly in H. with a tendency towards clonic spasm so frequently found when testing in the ordinary way. On the other hand, in some cases, Ac. is less relaxed in a dark room than when "fogged." Retinoscopy is also of great utility in cases where the visual power is so low that no satisfactory result can be at first obtained by the chart. The retinoscope will at once show the general nature of the error and, what is still more important, the presence of *high regular* or irregular As.

If the former, the approximate correction may be at once arrived at and this, when tried at the chart, will generally be found to have increased the vision to a degree rendering possible the ordinary routine. Also it may be occasionally found that clients have great difficulty in understanding what is required of them during the astigmatic test with the fan or diamond, and it is in such cases that the retinoscope is useful in obtaining information not available by other means. Again, if visual acuity is naturally bad, *i.e.* if, with the best possible correction, it is very subnormal, such correction is very difficult to arrive at subjectively. The answers are vague and the results uncertain—in fact the low acuity precludes anything but an approximate result. In these circumstances, therefore, the retinoscope will probably give a much closer correction.

Retinoscopic Difficulties.—Apart from the aberrations previously mentioned, the successful application of the shadow test is attended by certain difficulties. The chief of these is the unreliability of the average correction, unless made under atropine to insure that all accommodation be passive. Any correction found in the ordinary way with undilated pupils should always be carefully confirmed at the distance chart; sometimes the two will be found to agree almost exactly, while in others a considerable modification is necessary. On the other hand the strong aberration of a fully dilated pupil is sometimes confusing, and therefore the best conditions under which retinoscopy can be carried out is an intermediate dilatation between the normal and extreme; this would average about 5 mm. The small pupils generally encountered in older people are a serious stumbling-block and, in addition, the hazy media in later life render the reflex dull and uncertain. A very small pupil renders the application of retinoscopy almost impossible. Excessive pigmentation of the choroid, even with large pupils, may also render the test difficult owing to the abnormal absorption of light.

Differences between the retinoscopic and subjective corrections may be due to various causes; perhaps the most common is that of variable accommodative action. Another important factor is the inability to take the refraction along the visual axis owing to the strong contraction of the pupil so that, in some undilated cases, we are forced to project the beam somewhere in the region of the optic disc. But as the depth of the globe is seldom equal at the macula and disc, the corrections obtained at the two points may then vary even as much as perhaps 1 D. or 2 D., since it must be remembered that an axial difference of only ·3 mm. is sufficient to cause a dioptric difference of 1 D. in the refraction. To overcome this difficulty to some extent, the refraction should be taken as nearly as possible along the visual axis, and if secured in the region of the posterior pole no very serious difference can arise.

The obliquity of the light to the dioptric media may also be the cause of artificial As. in the crystalline lens, but this point has not been confirmed in any definite way. If it were so we should always expect to get more power in the horizontal meridian, but in practice this is by no means the case. However, since obliquity of the illuminating beam is liable to introduce error either of aberration or false depth of globe, it should be avoided as much as possible. Frequently, however, the reflex is very much brighter in oblique incidence, this being due to the relatively whitish appearance of the disc as compared with the surrounding fundus. Reflections from the cornea and trial lenses are often annoying to beginners, but they can always be got rid of by shifting position slightly.

Retinoscopic Calculations.

In the following the plane or Orthops mirror is presumed to be used; if the mirror is a short focus Cc., the movement is in every case the contrary, but the calculations are the same.

Now the shadow movement is *with* in all cases of refraction in which the P. R. is negative or, if positive, behind the observer's head. If the P. R. is between the observer and observed eye the movement is *against*. The shadow is neutralized when the P. R. coincides with the observer's position and to reverse the shadow it must be converted from *with* to *against* or *vice versa*.

The neutralizing lenses are those which under-correct M. or over-correct H. to a degree equal to the dioptric distance of the observer.

The correcting lenses are the neutralizing lenses plus a Cc. power equal to the dioptric distance of the observer.

If + 3 D. corrects, the neutralizer at 2 m. is + 3·5 D., at 1 m. it is + 4 D., at 50 cm. it is + 5 D. Conversely if + 4 D. neutralizes at 2 m. the required lens is + 3·5 D., if at 1 m. it is + 3 D., if at 50 cm. it is + 2 D.

If – 3 D. corrects, the neutralizer at 2 m. is – 2·5 D., at 1 m. it is – 2 D., at 50 cm. it is – 1 D. Conversely if – 3 D. neutralizes at 2 m. the required lens is – 3·5 D., at 1 m. it is – 4 D., at 50 cm. is – 5 D.

A reversing lens would be always ·25 D. more than the neutralizing lens, the latter being + or – according as the original movement, which has to be reversed, is with or against.

For example, a person requires O. D. + 2·5 S. ○ + 1·5 C. Ax. 90°; O. S. – 3·0 S. ○ – 2·0 C. Ax. 180°. The refractionist stands at 66 cm. so that the eyes must be made artificially myopic 100/66 = 1·5 D. in order that the shadow movements may be neutralized. The neutralizers are therefore O. D. + 4 Ver., + 5·5 Hor.; O. S. – 3·5 Ver., – 1·5 Hor.

If the original shadow movements are those found without any lenses in front of the eye and it is required to reverse the shadows, the powers must be O. D. + 4·25 Ver., + 5·75 Hor.; O. S. – 3·75 Ver., – 1·75 Hor. With these lenses O. D. is myopic 1·75 D. and O. S. myopic 1·25 D.

If the original movements were with the correcting lenses, they are all *with* and the first lenses which would make them *against* are O. D. + 4·25 Ver., + 5·75 Hor.; O. S. – 3·25 Ver., – 1·25 Hor.

Static Skiametry is the name generally used in the United States to denote the practice of retinoscopy in the ordinary way, and as already explained.

Dynamic Skiametry is retinoscopy performed so that the artificial myopia, needed for reversal, is obtained by causing accommodation for the plane of the mirror. The subject is fully and ably dealt with by Mr. A. Jay Cross in his work "Dynamic Skiametry," and Mr. Cross, who is an undoubted authority on the subject, claims advantages for the *dynamic* over the *static* method.

CHAPTER XIX

OPHTHALMOSCOPY

The Ophthalmoscope.

THE ophthalmoscope is an instrument employed for examining the fundus of the eye through the pupillary opening. In its simplest form it consists of a perforated concave mirror, similar to that used in retinoscopy, and for one method of ophthalmoscopy no other apparatus, except a lamp as source of illumination, is required. In the other method the only additional apparatus required is a strong convex lens, so that the retinoscopic mirror can, to a certain extent, be also employed as an ophthalmoscope, but for universal work, and for measuring the refraction objectively, a rather more elaborate instrument is needed having a battery of lenses running behind the mirror aperture.

When the concave mirror is used at the ordinary retinoscopic distance, the red fundus reflex only is seen, but no details are visible. This is due mostly to the very small portion visible through the pupil at that distance, but partly also to the fact that the emergent rays seldom have that divergence for which the observer's eye is adapted at the moment. In order, therefore, to overcome these difficulties and secure a detailed view of the fundus, we must either (1) approach the eye close to that of the client in order to widen the field of view, or (2) by means of a condenser form a real image of the fundus in the air, which can be brought easily within the range of distinct vision of the observer. The first is called the *direct* method, because it is actually the virtual image of the fundus that is viewed, and the second the *indirect*, since a real image of the fundus is seen through the medium of the condensing lens. In the direct method it may be necessary to employ additional lenses to render the image sharp, but in the indirect this is rarely necessary.

Direct Method of Ophthalmoscopy.—Here a small tilted concave mirror *M* (Fig. 111) is employed, the focal length of which is short, averaging about 3″. This is held as close as possible to the observed eye *O*, and light from a near source *S* is reflected into it such that the pencil converges approximately towards the nodal point *N*, whence it diverges and illuminates a considerable area *ab* of the fundus; the latter then diffuses the light, which emerges from the eye as in retinoscopy. In Em. the emergent light is parallel, in H. divergent, and in M. convergent, so that the distinctness of the image seen by the observer O' depends both upon his own refraction and that of the client. Since both may be Em., both Am. or one Em. and the other Am., it follows that only in certain circumstances will the observer obtain a clear view, and that when he is able to focus on his retina the light diverging from the observed fundus. It is therefore essential that the observer be himself Em., or rendered so by means of his correction, and also *that he be able to suppress all accommodative action at will.* Under these conditions his eye will be adapted for parallel light and, therefore, he will see the image of the observed fundus clearly only when the observed eye is also emmetropic, or rendered so by suitable lenses.

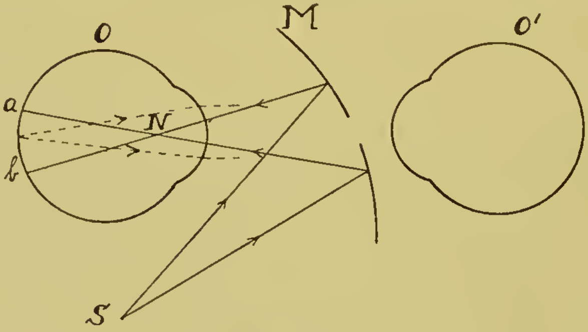


FIG. 111.

Assuming the observer's eye to be adapted for parallel light, we see, therefore, that light (Fig. 112) diverging from any point *A* on the fundus of an emmetropic eye will emerge parallel and focus at *B* on the retina of the observer, so that the latter receives a clear image of *A*. If there be M. the emergent rays will be convergent, and will focus in the vitreous at *B* (Fig. 113), while in H. they will be uncrossed when they meet the retina of the observer, but are tending towards a focus *B* (Fig. 114) behind it. In Am., therefore, lenses must be revolved into the sight-hole—Cx. in H. and Cc. in M.—in order that the emergent light may be rendered parallel, and thereby adapted to the observer. The nearer the two eyes the larger will be the field of view. The image seen is erect, virtual and magnified about 16 diameters, so that minute details can be seen by anyone with ordinary visual acuity, and if the observer moves his head from side to side the image apparently shifts in the same direction. A full discussion on the size of the

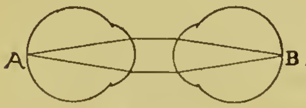


FIG. 112.

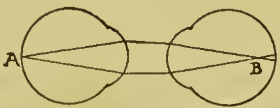


FIG. 113.

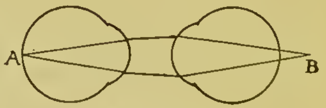


FIG. 114.

image, field of view, etc., will be entered into later, and for the present we will confine ourselves to the physiological aspect of ophthalmoscopy.

Although to simply obtain a view of the fundus it is not necessary for the Ac. to be fully relaxed, yet if the ophthalmoscope is to be used in measuring the refraction—as described later—it is absolutely essential that the observer should have his Ac. under complete control. The power to voluntarily relax the Ac. is a difficult one, and is only acquired after a good deal of practice; with objects at considerable distances it is easier, but the mental consciousness of a very near object is the chief source of trouble. Thus, theoretically, when an emmetrope views a small object through a + 20 D. lens, he would place it at its focal distance from the object, so that the light may emerge parallel; in the majority of cases, however, the object will be unconsciously placed within the focus so that the refracted light is more or less divergent, and this is caused by the mental appreciation of the nearness of the object, which induces a certain amount of involuntary accommodative action. This is, in fact, what happens in the direct method of ophthalmoscopy. The untrained observer is conscious of the proximity of the observed eye, and, therefore, generally accommodates strongly at first. The only advice that can be given is that, when employing the ophthalmoscope in the direct method, the observer should conceive the fundus to be situated at a great distance. A good plan, however, is to keep both eyes open, the eye not behind the mirror being directed towards the wall behind the client's head; at first only the wall will be seen, but after a while the fundus image, seen by the other eye, will be appreciated, especially if the illumination be so good as to give a brighter image than that of the wall.

The lamp should be on a level with the subject's ear and may consist of the ordinary retinoscopic aperture but, for preference, the naked light should be used, as the extent of fundus illumination is thereby increased. The client should look into the distance of the dark room in a direction about 3 inches to his left of the observer's right ear (if the right eye is being examined) so that his Ac. be relaxed as much as possible. Of course, if a mydriatic be used to dilate the pupil, and paralyze the Ac., the ease with which the examination can be made is vastly increased. In examining the right eye the observer must use his right, and for the left eye his left.

The Indirect Method.—This does not give so magnified a view of the fundus, and is practically useless for measuring the refraction. As a means of examining the fundus, however, it is more suitable for the optician than the direct method, and much more easily carried out.

The mirror used should be larger than in the direct method and of greater focal distance, say, 10 inches. This is used at about 20″ to 30″ from the observed eye, close to which a 3″ (13 D.) condenser is held by the left hand, the second, third and fourth fingers of which should rest on the subject's forehead for support. Light is now reflected from the mirror, through the condenser, and enters the eye very convergently, to diverge and illuminate a large area of fundus; in practice, however, it is often better to alter the distance of mirror so that a greater condensation of light may be thrown on the retina, whereon one may see a fairly distinct real image of the source. In Fig. 115, *M* is the mirror reflecting a convergent beam on to *L*, the lens, and thence to illuminate the fundus area *ab*. Light returning from any point *A* emerges and is brought, by the condenser, to a focus *B*, from which it diverges and is focussed at *B*′, on the observer's retina, by the aid of Ac. or an auxiliary Cx. lens rotated into the aperture of the mirror. Therefore the observer sees at *B* a real inverted image of the fundus, magnified about five times. This apparently moves in an opposite direction to that of the observer's head.

If the eye be Em. the image will be formed at the focal distance of the condenser—in this case 3″. If the eye be H. it is formed beyond the focus, and if M. within the focus, but the change in position of the image is comparatively slight, unless there be very high H., when the real image *B* may be formed so near to the observer that it may fall within his near point; in these circumstances a + lens must be revolved into the aperture to compensate for the nearness of *B*. As will be shown later, the magnification of the image depends both upon the refraction of the eye and distance of lens from the latter.

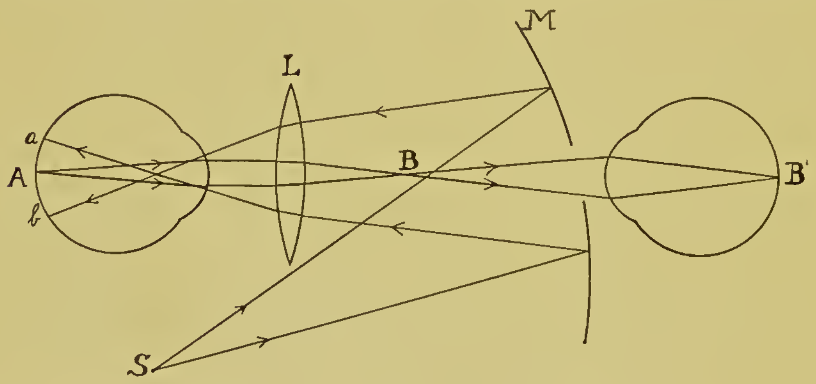


FIG. 115.

In practice the right, or better eye, can be employed to examine both those of the client, as the distance at which the observer works is too great to necessitate alternate use, as in the direct method. In viewing the fundus of the left eye, the client should be told to look just past the optician's left ear; this will bring the optic disc into view without further trouble. Similarly when the right eye is examined, the client should look past the little finger of the right hand, grasping the ophthalmoscope, the latter being held horizontally with its handle extending towards the right.

The Fundus.—In both methods the fundus of the eye is seen of a bright red colour, this coming, it is commonly supposed, from the bloodvessels and pigment of the choroid. It varies from dark to light red according to the complexion of the individual, being largely dependent on the amount of pigment in the choroid. In albinos the fundus is a very light yellowish-red, upon which the dark choroidal vessels are seen, there being an absence of pigment; while in negroes, owing to excessive pigmentation, the fundus appears brown, chocolate or even slate coloured. Between those extremes there are, of course, an infinite number of different shades.

In health the retina cannot be seen ; it is the vessels that constitute the details perceived in the healthy eye. The *optic disc* is the most conspicuous object on the fundus and should be looked for first; it is about 2·5 mm. in size and may be circular, but is generally oval with the long axis vertical. The disc is lighter in colour than the surrounding parts and is about 2·5 mm. from the posterior pole. In most cases two partial or complete rings can be seen surrounding it in health, the inner being the white (*scleral*) ring, and the outer the dark (*choroidal*) ring. The central retinal bloodvessels branch out from the *porus opticus* in the centre of the *lamina cribrosa.*

The arteries are smaller, less tortuous and lighter in colour than the veins, and have frequently a central white streak running throughout their length. The veins and arteries spread over the entire fundus with the exception of the macula area. Sometimes the disc itself is hollow—the physiological cup—which depression, however, does not involve the whole area ; it shelves on one side and does not reach the edge of the disc.

The macula is very difficult to see indeed but, when brought into view, there is generally a bright glistening reflex due, it is supposed, to the shelving edges of the fóveal depression. Without the reflex, it is seen as a small dark space and, under favourable conditions, the fovea can be distinguished as a tiny pinkish central spot. The approximate position of the macula can be found chiefly by locating that portion of the fundus, a little to the temporal side of the disc, where all the vessels are absent. The macula lies about 1·25 mm. to the temporal side of the posterior pole.

The sheaths from the optic nerve fibres cease where the latter issue from the lamina cribrosa ; they do, however, sometimes pass into the eye—opaque nerve fibres—causing snowy white patches at the edge of the disc. They lie in front of the bloodvessels and have brushlike extremities.

A white crescent-shaped ring on the side of the disc towards the macula is sometimes found, and this, being generally very much pronounced in myopia, is therefore called the *myopic crescent*; it is a highly exaggerated scleral and choroidal ring. It is caused by the separation of the choroid from the margin of the disc due to a stretching of the coats, and in high M. may completely surround the disc.

Difference in level of the fundus may sometimes cause a difference in the definition with which the various parts are seen in the direct method.

To overcome this different strength lenses must be turned up to render the indistinct portions clear.

Opacities.—Anything in the nature of an opacity of the cornea, lens, or vitreous is best shown up by using the large ophthalmoscope mirror at about 20″, without the condenser. A bright reflex is seen upon which the opacities appear on dark spots, striæ, etc., caused by the obstruction of light returning from the fundus.

The Mirror.—For ophthalmoscopic work the instrument should be accurate, and if used for the measurement of refraction, a good one is indispensable. It contains two mirrors, both concave, the one of 1″ to 1½″ in diameter, and of about 10″ focal length for use in the indirect method and in retinoscopy; the other is small, say, 1/2″ to 3/4″ in diameter with a focal length of about 3″. This is tilted and capable of rotation in its cell so that, for use in the direct examination, it may be turned to receive the light at the correct angle for each eye. The sight-hole is drilled perpendicularly to the plane of the instrument and therefore oblique to the mirror. The two mirrors are generally at opposite ends of an arm, pivoted around a central point, so that either can be brought into position. A battery of lenses is so arranged that a fair range of powers is available by combination of a few primary lenses. Usually, in the best ophthalmoscopes, the concaves range from ·5 D. up to 20 D., and the convexes from ·5 D. to 10 D. The various powers are revolved into the sight-hole by means of a milled head, or other device, capable of being put into action with one finger without taking the instrument from before the eye.

Correction of the Refraction in the Direct Method.—The accommodation of both client and observer is presumed to be completely relaxed and, in addition, the observer is presumed to be emmetropic, or rendered so by means of the necessary lenses. The correcting lens, therefore, is simply the strongest convex or weakest concave through which the details of the fundus are clearly visible. In order that the effectivity of the ophthalmoscope lenses may not differ from those subsequently worn, the mirror should be placed as near the observed eye as possible, so that the lens battery revolves practically in the anterior focal plane. If the opthalmoscope be held too far out, the measuring lenses will be too strong if concave, and too weak if convex.

Should the observer be ametropic, but not astigmatic, the lens giving the clearest view of the fundus under the above conditions will simultaneously correct client and observer and, therefore, the refractive error of the latter must be known in order to find that of the subject. Thus suppose the observer to be M. 2 D. and he finds that the correcting lens is apparently +4 D.; there must, therefore, be 6 D. of H. in order that the light may have a final divergence of 2 D. On the other hand if the observer were H. 2 D., the correcting lens would then be +8 D., since part has gone to correct each eye. If the two eyes have equal, *but opposite*, refraction, a clear image of the fundus is obtainable without any lens; thus a myope of 3 D. will see the fundus of a hypermetrope of 3 D., the rays from the latter having the necessary 3 D. of divergence. The rule is, that the excess or deficiency of the refractive power of the observer's eye is added to the strongest + or weakest − with which the fundus is seen.

In theory As. can be corrected by observing the relative distinctness of the retinal vessels, radiating from the disc, and spreading in all directions over the fundus, acting, so to speak, as a sort of astigmatic fan. In practice, however, this is exceedingly difficult and uncertain, and should rarely be attempted, as the result can be obtained with such comparative ease and accuracy by temporarily using the ophthalmoscope as a retinoscope. If, however, it is desired to try the experiment, that strongest + or weakest − spherical, rendering clear the vessels running in a certain direction, will be the correction for the *opposite meridian* of the eye, while that rendering the vessels, at right angles to the first set, equally clear is the correction of the other meridian. For example, it is found that with +3 D. the vertical vessels are seen clearly, but the horizontal blurred; suppose the horizontal to be cleared up with +5 D. Then the correction needed is +3·0 S. ◯ +2·0 C. Ax. 180°—in other words the axis of the cyl. is parallel to the most blurred set of vessels.

As a summary in the direct method—

If the fundus is seen clearly and a convex blurs, the eye is Em.

If the fundus is seen clearly and also clearly with a convex lens, the eye is H.

If the fundus is seen indistinctly and rendered clear by a Cx. lens, there is H.

If the fundus is seen indistinctly and rendered clear by a Cc. lens, M. is indicated.

If, with or without a lens, some vessels are seen clearly and not others, there is As.

Estimation of the Refraction by the Indirect Method.—Theoretically this is possible, but practically, owing to the uncertainty of the results and the difficulties in observation, it is of very little use indeed. This method is based on the fact that, unless the observed eye be Em., a withdrawal of the condenser produces a change in the size of the image. The reason for this is that, since the rays from an Em. eye are parallel and the far point at ∞, no change in the position of the condenser can affect the size of image, because the latter is always formed at the same distance from the lens.

In M., however, the emergent rays are convergent towards the P. R. and the final aerial image is formed within the principal focus; in these circumstances, by withdrawing the lens, the image must *increase* in size and, theoretically, the correcting lens is the weakest concave arresting all such change. On the other hand, in H. the light emerges divergent as if from the virtual far point behind the head, the P. R. in this case serving as a natural object with respect to the lens. The aerial image is thus formed beyond F of the condenser, so that, on withdrawal of the lens, the image decreases in size and the strongest Cx., causing it to remain constant, is the correction. In astigmatism the image of the disc will be seen to enlarge more in one direction than in another, so that, if round, it would appear oval in shape, the long axis corresponding with the meridian of minimum power.

Of course, a slight *increase* in the apparent size of the image in all cases arises from the fact that, as the lens is withdrawn, the image approaches the eye and therefore subtends a larger visual angle. In general, however, the increase due to this factor may be ignored as being too small materially to affect the result.

The Ophthalmoscopic Image.

We have previously mentioned that the image seen with the ophthalmoscope is magnified about 5 diameters in the indirect, and about 16 in the direct; also in the indirect method certain changes in the size of the image take place when the condenser is moved relatively to the eye. It is with the magnification, and variations in the size, of the ophthalmoscopic image that the present article has to deal.

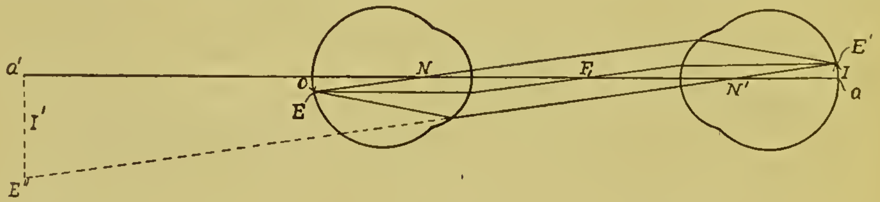


FIG. 116.

Direct Method.—For simplicity we will assume the two eyes to be emmetropic, and at a distance apart equal to the sum of their anterior foci, so that the focal points themselves coincide in F_1 (Fig. 116). Let O be any portion of the illuminated fundus—say, the optic disc. Then any ray from E parallel to the axis will, after refraction, pass through F_1, and this point being the anterior focus of the observer's eye, the ray will be refracted parallel to the axis, and will reach the retina in E' such that I is the image of the original object O. If the static refractions of both eyes are equal, then the image I received by the observer will be identical in size with that of the object O and, since the issuing rays from O are parallel, the distance between the two eyes is immaterial. The size of I does not alter, in this case, as the observer approaches or withdraws; the only result is a greater or lesser field of view.

Now the observer's retinal image I is projected to his distance of most distinct vision I', and if this distance be taken as the usual average of 250 mm., we obtain the apparent magnification from the ratio between I' and I, that is—

$$M = \frac{I'}{I} = \frac{N'a'}{N'a} = \frac{250}{15} = 16 \text{ approx.}$$

If the projection of the image is to a distance greater or less than N′a′, the magnification is greater or less than 16 diameters. It will be seen that O, the object, *i.e.* the portion of the observed fundus, I, the retinal image of observer, and I' the final projected image, are all formed under the same angle.

Thus we see that the image, when both eyes are emmetropic and separated by any distance, is magnified about 16 times. If, however, there is Am., the fundus can only be clearly seen with the necessary correcting lens placed between the eyes, in the aperture of the ophthalmoscope. If this be done, and the lens situated exactly at F_1 of the observed eye, the image seen is the same size as in Em. but, if the lens is placed beyond F_1, then the magnification is slightly greater in M., and less in H., than in Em. This will be seen from the next diagram. Fig. 117 represents the observed eye, of which *ab* is the portion of the fundus forming the object. Parallel rays from *a* and *b* meet in F_1 the first focal plane, such that AF_1B is the angle under which the image is seen by the observer. If now the eye be H. or M., rays from *a* and *b* parallel to the axis still cross at F_1, but the image will be blurred owing to the general divergence or convergence of the light. If, however, the correcting lens L in the ophthalmoscope be situated at F_1, the angle subtended by the image will be the same as in Em. and therefore the magnification is unchanged; the image is simply rendered sharp by the correcting lens. Generally, however, the lens is situated beyond F_1 of the observed eye, and in that case the angle AF_1B, subtended by the image, is altered in size. In M. the correcting concave diverges the *containing* rays A and B to MM' and thus enlarges the angle, and consequently the retinal image of the observer. On the other hand A and B are rendered less divergent by the correcting convex in H., so that the image is seen smaller than in Em. The greater

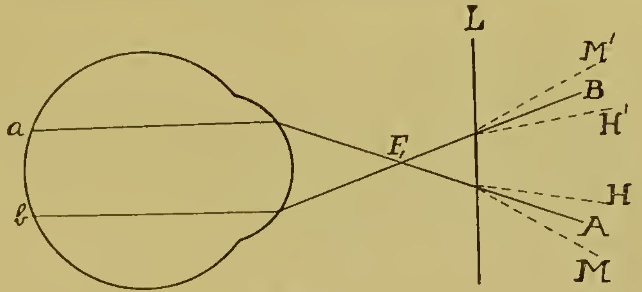


Fig. 117.

the distance of the lens beyond F_1 of the observed eye, the greater will be the magnification in M. and the less will it be in H. Were it possible to place the correction within F_1, we should obtain a relative magnification in H., and a corresponding diminution in M., because a convex would then increase, and a concave reduce, the angle AF_1B. A special discussion on this point will be found later on in this chapter.

Area of Fundus Seen.—The extent of the fundus seen is directly proportional to the size of the pupil of the observed eye, and inversely proportional to its axial length. This can be seen from Fig. 118, in which *ab* is the pupil of the observed eye, and *N* the nodal point of the observer. Then the geometrical image *b'a'*—received on the observer's retina—of the observed pupil is found by drawing straight lines from the edges of the observed pupil through *N*, and the area of fundus seen must lie between those rays *Aa*, *Bb*, which, after refraction, will just pass through *N* as *aa'* and *bb'* These areas are *AB* in Em., *A'B'* in H. and *A''B''* in M., showing that the extent of fundus seen is largest in H. and smallest in M.

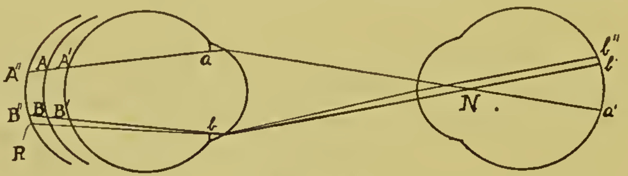


Fig. 118.

But although we say that *b'a'* is the image of the observed pupil containing the area seen, yet it must be noted that rays capable of entering the observed eye are not limited strictly to *Aa* or *Bb*. Some other ray *R*, lying slightly outside *Bb*, can also enter the observed eye and impinge on the retina at, say, *b''*. The zone *b'b''* is that in which the image diminishes in intensity—in other words, it is part of the fuzzy image of the pupil *ab*, through which the area *B''R* is seen. Therefore the fundus seen is not bounded by a hard-and-fast circle, but by a diffused border allowing slightly more of the fundus *AB* to be seen, than is geometrically indicated. Indeed we may say, therefore, that the extent of image is also, to a slight degree, dependent on the size of the observer's pupil, since this latter governs the width of the zone *b'b''*. From what has been said the value of a mydriatic in dilating the observed pupil will be appreciated.

The extent of image is also governed by the position of observer, it being inversely proportional to the distance between the two eyes. The nearer the observer, therefore, the greater will be the extent of fundus visible and *vice versa*. This will be seen from Fig. 118, because if *N* be nearer, the rays from *a* and *b*, passing through *N*, must proceed from points wider apart, indicating a simultaneous increase in the size of the pupillary image *b'a'*, and the extent of field contained therein, *i.e.* pencils diverging from extreme points of the fundus can enter an eye sufficiently near, but would escape entering one at a greater distance.

The Image in the Indirect Method.—We have said that, in the indirect method, the light emerging from the observed eye is brought to an aerial image by a strong condenser, from which image it diverges to the observer. The latter, therefore, must accommodate for some point between himself and the lens, and should his amplitude be insufficient for the purpose, he must turn a convex lens into the ophthalmoscopic aperture. Let us first imagine both eyes to be emmetropic. In Fig. 119, let *ab* be the portion of illuminated fundus under consideration, *N* the nodal point, F_1 the anterior focus and *L* the condenser; suppose *L* to be a certain distance in advance of F_1. Then light diverging from *a* will issue parallel from the eye to focus at *a′* in the focal plane of the condenser; *b′a′* is therefore the inverted image of *ab*, and *a″b″* the erect retinal image of the observer, secured by accommodation for the plane of *b′a′*. The observed fundus *ab* is therefore seen inverted. Owing to the limitations of space, Fig. 119 is necessarily very diagrammatic, the aerial image *b′a′* and the observer's image *a″b″* being, of course, in practice much larger than the fundus area *ab*. The distance F_1L should also be considerably greater than shown.

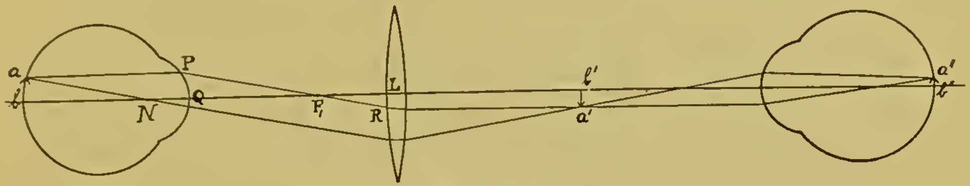


FIG. 119.

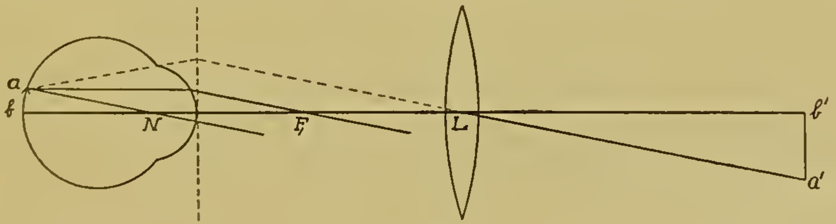


FIG. 120.

If the condenser *L* is placed a distance from F_1 equal to its own focal length, as shown in Fig. 119, the ray *aP*, parallel to the axis, is refracted through F_1, which is also the anterior focal point of *L*. The ray, therefore, finally emerges from the condenser again parallel to the axis as *Ra′*, so that *a′* is the focus for all light diverging from *a*.

Size of the Image in Emmetropia.—Since the light from the observed eye emerges parallel, the ray, such as *La′* (Fig. 120), that can pass through the optical centre of the condenser L must always make the same angle $b'La'$ with the axis; further, the aerial image $b'a'$ must always be formed at the focal distance Lb', no matter what the distance of the condenser from F_1 may be. Therefore as the lens is withdrawn from an emmetropic eye the image must remain the same size.

Now since the angles aNb and $a'Lb'$ are equal, we have the magnification—

$$M = \frac{b'a'}{ab} = \frac{Lb'}{bN}$$

But Lb' is 77 mm., the power of the condenser being generally about 13 D., and bN is taken as 15 mm. Therefore—

$$M = \frac{77}{15} = 5 \text{ approx.}$$

Thus, in emmetropia, the optic disc is seen as an image about 10 mm. in diameter, situated at the distance of distinct vision of the observer; it is mentally projected to the plane of the condenser and is apparently formed there, just as the reflex in retinoscopy is projected to the pupillary aperture. Of course, the actual size of the observer's retinal image also depends upon the angle which the image subtends at his nodal point, so that a person with a close near point, or who uses a convex lens in the ophthalmoscope, secures a relatively greater magnification over one who has not these advantages.

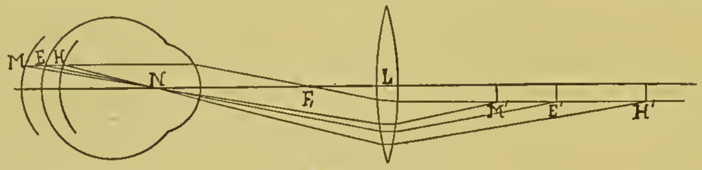


Fig. 121.

Size of the Image in Ametropia.—In ametropia, of course, the relative magnification is altered for any given position of the condenser, as compared with Em.

It can be shown that the aerial image formed by the condenser must be the same size in all refractive conditions *provided that the condenser is at its own focal distance from the anterior focus* F_1 *of the eye.*

In Fig. 121, let M, E and H represent the retinæ in M., Em. and H. respectively; F_1 is the anterior focus, L the condenser and LF_1 its focal length. Then any ray parallel to the axis within the eye must, after refraction, pass through F_1 to be again rendered parallel to the axis by the lens. Another ray from E passing through the nodal point N will meet the refracted ray in E' in the principal focal plane of L, so that E' represents the plane of the image. M' and H' are the images from the myopic and hypermetropic eyes, M' being within and H' beyond the principal focus of L.

But all three images, being contained between the axis and the parallel line *M′H′*, must be of equal size. Were it possible, however, to reproduce practically the three conditions shown in the sketch, the hypermetropic image would appear slightly larger, and the myopic image slightly smaller, on account of the difference in the visual angle subtended by them at the observer's nodal point. Figs. 121 to 123 are slightly out of proportion and should show $LF = LE'$, and both great compared with NF_1.

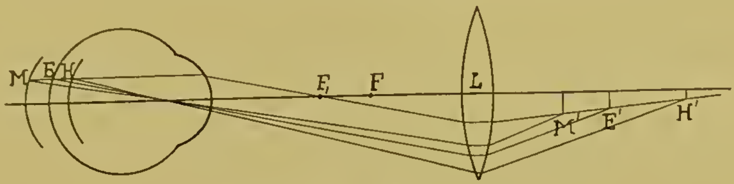


FIG. 122.

Change in Size of Image in Ametropia.—Now suppose the condenser be withdrawn from the observed eye; for simplicity we will consider the latter to embody all three conditions of H., Em. and M. as in the last diagram.

In Fig. 122, F and F_1 are now separated, L being withdrawn from the observed eye. In these circumstances the ray passing through F_1 is rendered convergent by the lens and takes up a direction $M'H'$ inclined towards the principal axis. The secondary axes through N meet $M'H'$ in M', E' and H' as before, but it can be seen that now the myopic image M' has increased, and the hypermetropic image H', decreased in size by advancement of the lens; in addition both are now nearer to L than before. The emmetropic image E' however, undergoes no change either as to its size or position with respect to the lens since the light incident on the condenser is parallel. Thus we obtain the rule that in examination by the indirect method, *an increase in size of the image on withdrawal of the condenser denotes* M. *and a decrease* H. Em. is characterized by no change in size. If, on the other hand, the condenser L is placed nearer the observed eye, so that F_1 falls within F, the converse condition obtains, H' enlarging and M' diminishing. This can be seen, without explanation, from Fig. 123 which shows the ray passing through F_1 to be divergent from the axis after refraction by the condenser. As before, E' undergoes no change.

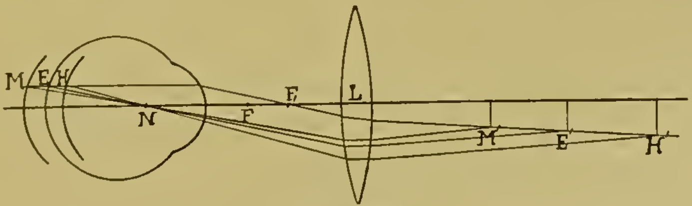


FIG. 123.

The lower the degree of H. or M., the more nearly does the light from the eye approach parallelism, and the nearer is the image in position and size to that obtained in Em. In very high H. the light is so divergent that the aerial image is far from the condenser, and correspondingly near the observed eye, and a stronger lens than 13 D. is advisable, or it may not be seen at all. If the condenser were placed so that its focal point coincides with the P. R. of the H. eye, the light, after refraction, would be parallel and no real image formed.

In high M. the light emergent from the eye is very convergent, and the condenser has little effect on the position and size of the image; indeed if the lens be at the P. R. it has no effect, the image being in the plane of the condenser, and if placed beyond the P. R. no real image on the side of the observer is obtained at all. In M., therefore, a weaker lens than +13 D. gives better results; indeed, when the error is medium to high, the fundus details can be seen without any lens. In this case the observer simply examines the natural real image of the fundus formed by direct convergence from the eye, but the field of view is very small unless the pupil be widely dilated.

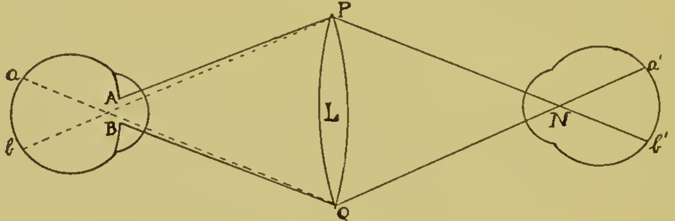


Fig. 124.

Extent of the Field in the Indirect Method.—Unlike that in the direct method, the field in the indirect is only dependent to a small degree upon the size of the pupil. Theoretically its extent is only limited by the size of the condenser, but in practice a very large lens is difficult to manipulate and one $2\frac{1}{2}''$ in diameter will be found to be ample. Larger sizes suffer too much from spherical aberration to be of any use.

In the indirect examination it will be found that, as the condenser is withdrawn from the observed eye, the virtual image of the pupil, seen through it, rapidly increases in size until it entirely fills the lens and disappears; a further withdrawal of the condenser brings into view the *real* image of the pupil and surrounding iris. In Fig. 124, the condenser *L* is in a position such that, to the observer, the virtual image of the pupil *AB* entirely fills the lens. The rays *AP* and *BQ* are supposed to be so refracted that they cross at *N*, the nodal point of the observer, forming the image *a′b′*, within which is contained the image of practically all the fundus between *ab* of the observed eye. Thus, for the same power, the greater the diameter of the lens the greater is the field of view, *i.e.* the condenser itself limits the field. Theoretically therefore, the field is quite independent of the size of pupil, but in practice it is very difficult to hold the lens so that a small pupil may be made to entirely disappear; the slightest movement of the condenser or of the observed eye immediately brings the iris into view again on one side or the other. The installation of a mydriatic enormously facilitates the examination, but a careful observer will get very good results from undilated pupils.

Success with the indirect method depends largely upon the relative powers of the lens and mirror employed, their distances from the eye and position of source. We have seen that, for a maximum field, the lens must be so situated with respect to the pupil that the image of the latter fills the lens. In addition, to get the best possible illumination, the light from the source, after reflection from the mirror and transmission through the lens, should be convergent towards some point in the vitreous a little in front of the retina so that, on the latter, a real and approximately sharp image may be formed. To satisfy both these conditions simultaneously is by no means easy in practice, but with a + 13 D. lens and a 10″ Cc. mirror a distance between them can be found that will give the best results. A fertile source of annoyance, especially to beginners, lies in the reflections from the surfaces of the condenser and cornea, but these can, with practice, be turned aside by slightly tilting the condenser and mirror.

The Direct Image in High Ametropia.—Under certain conditions the image in the direct method is difficult or impossible to see; this, apart from smallness of the pupil, is generally caused by the magnification being too high in M., or is due to the impossibility of neutralizing the great convergence of the emergent light in high M. Similar difficulties do not occur in H., firstly because high errors are rare, and secondly because the divergent light is easily overcome by a convex lens, which also causes a reduction in the magnification. Thus suppose a case of 10 D. of myopia, the far point being 4″ from the eye. The lens necessary to correct the Am. at the usual distance of 15 mm. would be about − 12 D., but as the ophthalmoscope is rarely held so close to the observed eye, a still more powerful lens would be necessary to neutralize the convergence of the emergent light; thus supposing the ophthalmoscope to be used at 2″, we should have to turn up − 20 D. in order to get a clear view of the fundus. But although the details are visible, the field of view is small on account of the high magnification.

Let F_1 (Fig. 125) be the anterior focus, R the distance of the P.R. and d that of the lens from the cornea or, more exactly, from the refracting plane. Then the correcting lens, or that lens rendering parallel the light from a portion of the observed fundus O, will have a focal distance of

$R-d$. Thus the greater is d, the more powerful must be the concave lens, in order that the convergent light from the myopic eye be rendered parallel.

Now the angle under which the image would be seen in emmetropia, or in any state of refraction provided the correcting lens were placed at F_1, is θ. When, however, a more powerful concave is substituted beyond F_1 in myopia, the angle under which the image is seen is increased to θ' and therefore we may represent the increase in magnification by the ratio θ'/θ. But since these angles are small in practice we can substitute for θ'/θ, the ratio F_1L/QL. But QL is the conjugate focal distance of LF_1 by refraction through the lens, *i.e.* $1/QL = 1/F + 1/LF_1$, where F is the focal length of the correcting lens. From this we find $LF_1/QL = (F + LF_1)/F$.

Then since $LF_1 = d - F_1$, and $F = R - d$, we have—

$$\frac{\theta'}{\theta} = \frac{R - F_1}{R - d} \text{ or } \frac{F + d - F_1}{F}$$

This expression represents the *additional* magnification obtained over and above the 16 diameters given in ordinary circumstances.

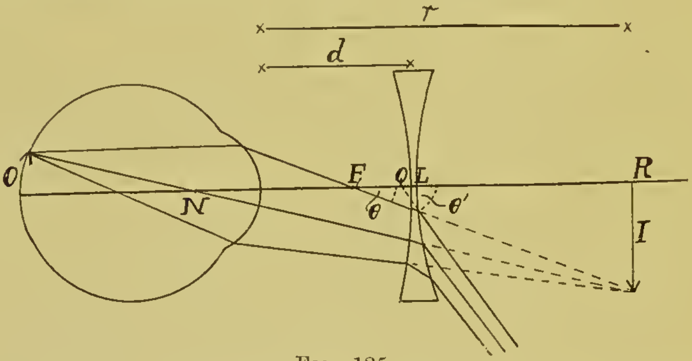


FIG. 125.

Thus, in the previous example, let us imagine the ophthalmoscope to be held 2″ from a myopic eye whose far point is 4″. Taking F_1 as 15 mm. we have—

$$\frac{\theta'}{\theta} = \frac{100 - 15}{100 - 50} = \frac{85}{50} = 1{\cdot}7$$

i.e. the total magnification obtained would be $16 \times 1{\cdot}7 = 27$ approx., and the field of view would be correspondingly reduced, so that only a very small portion of the fundus would be observable without moving the head.

Again suppose a case of 20 D. M. where the P. R. is 2″. With the ophthalmoscope held at 2″, the magnification would be infinitely great and the field infinitely small—in other words, nothing whatever would be seen. If the ophthalmoscope be held $1\frac{1}{2}$″ from the eye, we should require $F = 50 - 37{\cdot}5 = 12{\cdot}5$ mm. or -80 D. to give us a clear image under a magnification calculated from the above expression, of, approx., 50. In practice, of course, no such lens is found in the ophthalmoscope and, therefore, the instrument must be approached still closer to the observed eye until the power of lens required falls within the range of those supplied.

It will be noticed that the conditions discussed above are identical with the principle of the ordinary opera glass, the observed dioptric system corresponding to the objective, and the ophthalmoscope lens to the eye-piece. Similarly high H. gives a small direct image, since we get reduction in the same way as looking through the wrong end of an opera glass; here the dioptric system acts as the eye-piece and the convex ophthalmoscope lens as the objective.

In practice the difficulty, experienced in high ametropia, is eliminated by putting the approximate correction up in a trial frame as close to the eyes as possible, and then proceeding as for Em. and low errors of refraction. We then have normal magnification and normal field of view but the illumination, in the case of M., will be poor.

CHAPTER XX

THE RETINAL IMAGE

In most optical instruments the surrounding medium is air, the anterior and posterior equivalent foci E_1F and E_2F are equal, and the nodal points lie in the equivalent planes; the size of image produced by the lens system is governed then by the distance of the conjugate foci from the adjacent equivalent points as shown in Fig. 126, where AB is the object and $B'A'$ its image. When AB is at ∞ the distance E_2B' is the posterior principal focal distance.

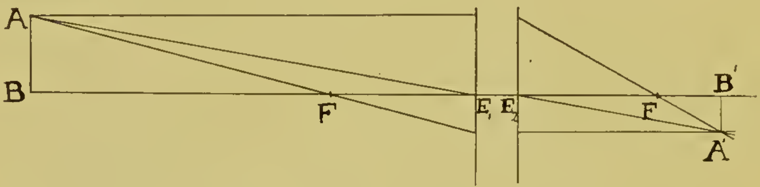


Fig. 126.

The eye differs from the great majority of optical instruments in that the anterior and posterior foci are not formed in media of the same optical density, the anterior being in air whose refractive index is 1, and the posterior in the vitreous, the refractive index of which is 1·333.

In this case, the nodal points are displaced from the equivalent planes and the size of the image depends on its distance from the adjacent nodal point, since the undeviated secondary axes controlling the size of the image cross there.

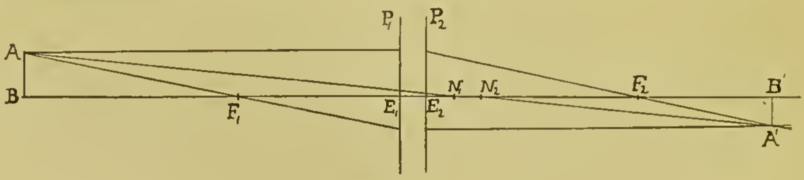


Fig. 127.

Fig. 127 shows the relative position of the cardinal points. E_1E_2 are the principal points, P_1P_2 the principal planes, N_1 and N_2 the nodal points, while F_1 and F_2 are the anterior and posterior principal foci respectively. If the anterior focal length E_1F_1 be taken as 15 mm. and the posterior E_2F_2 as

20 mm. the refracting power is 66 D. for light emerging from the eye and 50 D. for light entering.

The difference of the foci is due to the difference in the density of the first and last media, the ratio of the refractive indices 1 : 1·333, being the same as that of the foci 15 : 20. This being the case, the nodal points are shifted towards the denser medium, the vitreous, by an amount equal to the difference between F_2 and F_1 or $20 - 15 = 5$ mm. The posterior nodal point is thus 15 mm. from the retina and therefore the image produced is the same as would be formed by a lens of 66 D. in air. In other words, *the size of the retinal image is controlled by the anterior focal length F_1 as the distance from F_1 to E_1 is the same as that from N_2 to F_2.* On the other hand the image produced by refraction from the vitreous into air would be identical with that formed by a lens of 50 D. situated in air.

It is usual to consider H. and M. as due to a deficient length of optic axis in the former and to an excessive length in the latter, the posterior focus F_2 falling respectively behind or before the retina when accommodation is at rest. But the error may arise from an excess, or lack, of refractive power due to variations in the radius of the cornea and lens, density of the media, etc., and it is necessary to clearly keep these two main causes in view when dealing with problems connected with the size of the retinal image.

For instance, imagine three eyes which are respectively Em., M. and H., the Am. in the latter two being due solely to differences in axial length. Then, with accommodation at rest, each will form images equal in size in virtue of the equality in their dioptric powers, but the images of a distant object will not be clearly defined in the H. and M. eyes, since they do not fall on the retina.

The hypermetrope, however, with the aid of his Ac., increases his refraction sufficiently to bring the image forward on to the retina, but at the same time *he shortens his anterior focus and therefore obtains a smaller image than the emmetrope.* The myope is unable to obtain a sharp retinal image of a distant object.

Now let the three eyes view some object at such a distance that all three can obtain a clear image, *i.e.* let the object be at the far point of the myope. Then the latter, which exerts no Ac., has the largest retinal image, the emmetrope coming next and hypermetrope has the smallest. If, however, the hypermetrope and emmetrope both relax their Ac., and we imagine the retina removed, then the size of the image is the *same* as that of the myope.

If the Am. is refractive, the axial length of globe being the same in each case, the conditions just described are reversed. Here, when Ac. is relaxed in the three cases, the image formed in the vitreous of the myopic eye is the *smallest* of the three, the emmetrope being next and the hypermetrope having the largest, if in the last condition the retina were removed to allow of its formation. When an object, whose distance equals the P. R. of the myopic eye, is viewed, the hypermetrope and the emmetrope, by means of accommodation, shorten the focal length of the eye sufficiently to enable the image to be formed on the retina, and all three images are equal in size. The latter occurs provided the extra power obtained by means of the Ac. does not merely shorten the focus of the eye but also places the nodal points in the same position as those of the myopic eye.

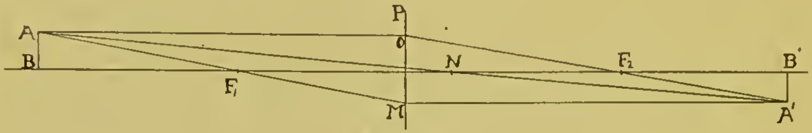


FIG 128.

Let the effect of lenses placed in front of the eye, on the size and position of the retinal image, be now considered. In Fig. 128 let P be the united principal plane of the eye, N the united nodal point F_1, and F_2 the anterior and posterior principal foci. The image of an object AB is easily constructed by tracing the course of three known rays AO, AN and AM. AN is a

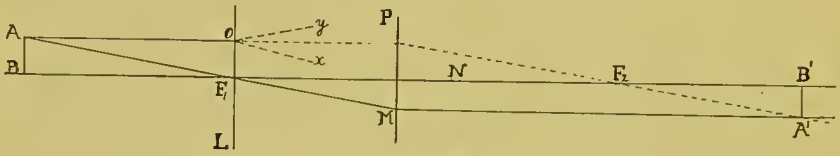


FIG. 129.

secondary axial ray passing undeviated through N, AM passes through F_1 and is refracted parallel to the principal axis BB' while AO, parallel to BB', is refracted to pass through F_2. The point of intersection A' is the image of A and $B'A'$ is the inverted image of AB. Now if a thin lens L of any power or sign be placed so that its optical centre coincides with F_1, as in Fig. 129, the image will not be altered in size, since the direction of the ray AM is

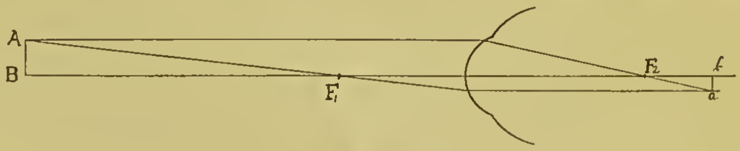


FIG. 130.

unchanged by the lens, it passing along a secondary axis of the lens itself. The image $B'A'$ is merely brought forward if the lens is convex, or carried backwards if the lens is concave, AO being converged towards x or diverged towards y respectively by the lens.

In Fig. 130 AB is the object and ba the image in an eye without a lens. Fig. 131 is the same having a Cx. lens in the anterior focal plane, the image *ba* being drawn forward but unaltered in size. In Fig. 132 the effect of the Cc. is to throw *ba*, still the same size, farther back from the cornea.

We therefore obtain the important rule *that a lens placed in the anterior focal plane of the eye has no effect on the size of the image formed, the latter being merely moved forwards or backwards as the case may be.* The image is then the same size as in Em. If, therefore, in a case of *axial* anisometropia, we could place the correcting lenses exactly at the anterior focus of each eye, the retinal images, ignoring the effects of aberration and distortion produced if the lenses were strong, would be identical in size. Under these conditions the effect of a convex lens is merely to reduce, and that of a concave to increase the divergence of the light, from each point of the object, incident on the dioptric system of the eye.

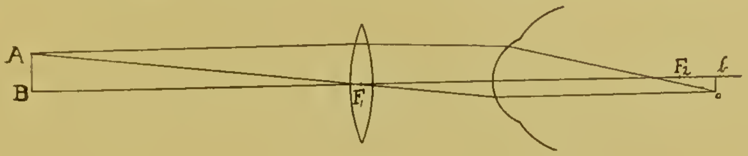


FIG. 131.

It is not possible to make a comparison of the sizes of the images formed in many cases because they may not be sharply formed at the retina. In the following epitomized comparisons a distinction must be drawn between *I*, the ocular image actually formed by the dioptric system in the vitreous or presumed to be formed behind the retina, and the image formed at the retina. If the retina is not coincident with *I*, the blurred retinal image, owing to the confusion circles, is larger than *I*:

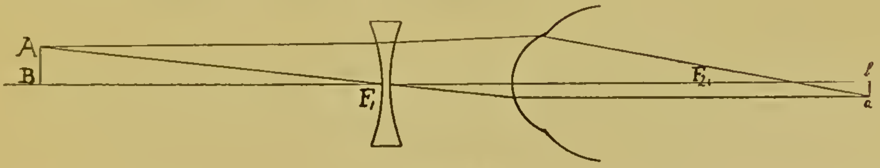


FIG. 132.

In axial H. and axial M., *I* is the same as in Em.

In refractive H., *I* is larger than in Em.

In refractive M., *I* is smaller than in Em.

In refractive H., *I* is larger than in axial H. when both are accommodated for clear vision.

In refractive M., *I* is smaller than in axial M. when both see clearly the same near object.

In axial H. (accommodated), *I* is smaller than in Em.

In refractive H. (accommodated) *I* is practically the same as in Em.

In axial M., *I* of a near object clearly seen is larger than in Em.

In refractive M., *I* of a near object clearly seen is smaller than in Em.

In axial H. and axial M. corrected by a lens at F_1, I is the same as in Em.

In refractive H., similarly corrected, I is larger than in Em.

In refractive M., similarly corrected, I is smaller than in Em.

In Em., for near vision, I is larger with a Cx. lens than when accommodated.

In H., I is larger with a Cx. lens than when accommodated.

In M., I is smaller with a Cc. lens and accommodated than without the lens.

Correcting Lens within or beyond F_1.—Ametropia can, of course, be corrected by a lens not coincident with F_1 but, for the same error of refraction, a convex lens must be weaker and a concave stronger the farther it is withdrawn. Thus if H. be corrected by a lens beyond F_1, that lens must be weaker than the one required at F_1 itself, but a convex within the anterior focus must be stronger than that required at F_1. Similarly the correcting concave in M. beyond, or within, the anterior focus must be stronger or weaker respectively than the lens required at F_1, to bring the image to the retina.

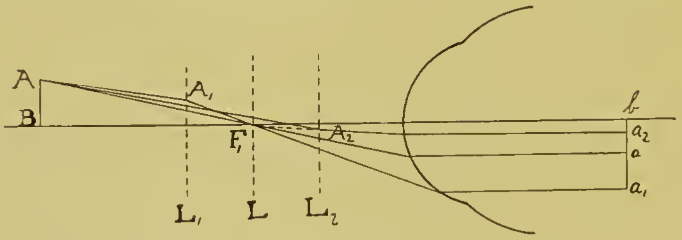


Fig. 133.

Thus in Fig. 133 L, L_1, L_2, are three convex lenses situated at, beyond or within F_1 respectively, and it is presumed that all three correct the Am. L_1 being weaker and L_2 stronger than L. Therefore the three images ba, ba_1 and ba_2 are formed at the same distance behind the principal plane but are of different sizes, that due to L_2 being the smallest and that to L_1 the largest. If the Am. is corrected by L at F_1 and the eye is moved backwards the image moves forward and enlarges; if the eye is advanced the image moves backwards and diminishes. Fig. 133 is necessarily exaggerated in order to render the action of the lenses clear. The ray AF_1 passing directly through F_1 causes the image to be formed at a. A ray AA_1 refracted at L_1 passes through F_1 and causes the image to be formed at a_1 and therefore larger. A ray AA_2 refracted at L_2 proceeds as if from F_1 and causes the image to be formed at a_2 and therefore smaller.

Fig. 134 also exaggerated, illustrates the corresponding action of three correcting concaves whose positions vary with respect to F_1. The lens L_1 is presumed to be stronger, and L_2 weaker than L and therefore, as placed, all correct the Am., the ocular image in each case being equally distant from the refracting plane, but of varying size, ba_1 due to L_1 being the smallest and ba_2, due to L_2 being the largest. If L at F_1 corrects the Am. and the eye is moved backwards, the image moves forward and diminishes; if the eye is advanced the image moves backwards and enlarges. The ray AF_1, passing directly through F_1 causes the image to be formed at a. A ray AA_1 refracted at L_1 passes through F_1 and causes the image to be formed at a_1 and therefore smaller. A ray AA_2 refracted at L_2 proceeds as if from F_1 and causes the image to be formed at a_2 and therefore larger.

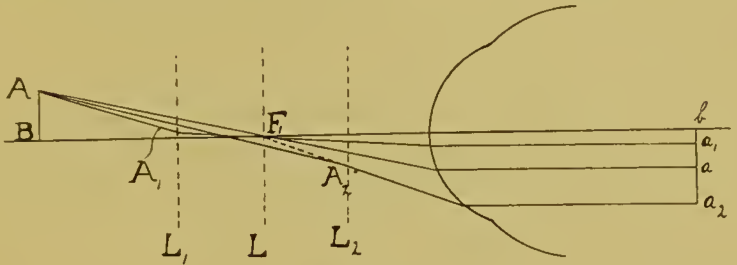


Fig. 134.

We may therefore summarize the rules that—
If the image is formed at the same distance by—
(*a*) A Cx. lens placed in front of F_1 the image is larger.
(*b*) A Cx. lens placed behind F_1 the image is smaller.
(*c*) A Cc. lens placed in front of F_1 the image is smaller.
(*d*) A Cc. lens placed behind F_1 the image is larger.

The above—apart from effectivity—account for the fact that the presbyope and hypermetrope move Cx. lenses out from the eyes, and the myope pushes them nearer, as by so doing they obtain larger retinal images.

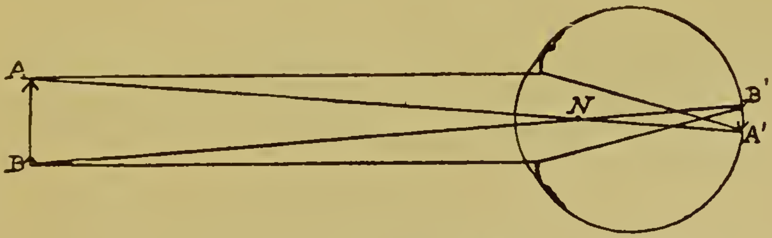


Fig. 135.—Diagram showing the Course of Rays from an Axially-placed Object to the Retina.

A B is the object, and *B'A'* the inverted retinal image. *N* is the nodal point.

Approximate Calculation for the Retinal Image.—The object and its image subtend equal angles at the nodal point, so that the image of an object, which subtends a given angle at N, depends on the distance which the axial rays travel before the image is formed. If the latter is at the retina the size of the retinal image is to the size of the object as the distance between the nodal point and the retina is to the distance between the nodal point and the object. Taking the nodal point of the reduced eye to be 15 mm. from the retina—

$$I = \frac{\text{size of O} \times 15}{\text{distance of O}} = \frac{15\ O}{f_1}$$

where I is the size of the image, O that of the object and f_1 the distance of the object from the nodal point. The size and distance of the object must be expressed in the same terms—viz., yards, metres, etc.—and the result is always in mm. as is the distance of I.

Since the distance of P to N is so very small compared with that of a distant object, it is usual to ignore it and write the formula as if the distance of O were measured from the cornea, or refracting plane, of the emmetropic eye. If the object AB be 10 cm. long and 6 m. from the refracting plane then its image B′A′ is

$$I = \frac{15 \times 10}{600} = \cdot 25 \text{ mm.}$$

More Exact Calculations.—The foregoing calculation is not, of course, strictly accurate. The formula for calculating the size of the retinal image, deduced from the relation existing between the distance of O to nodal point and nodal point to retina, is only true providing the object is at such a distance that no Ac. is exerted and the length from cornea to nodal point is so small as to be negligible. When, however, the object is brought sufficiently close, these assumptions are no longer possible and the expression breaks down since, either the image is no longer formed sharply at the retina, but behind it, owing to the advance of the object, or the image is formed sharply at the retina by means of Ac. The focal lengths of the system, in this latter case, are shortened, the nodal point is advanced and the distance of the image from the cornea, although the same as when the object was at ∞, is now a posterior conjugate focal distance and not a principal focal distance. Also the distance of cornea to nodal point, being comparable with that of the object, can no longer be neglected as it is in the above formula.

FIG. 136.

The following, as will be seen, includes the necessary corrective factors so that the final result, based upon the influence of the anterior focal distance on the size of the retinal image, is of universal application.

Let *Bx* (Fig. 136) be the principal axis of a reduced eye of which *P* is the cornea (or refracting plane) and *R* the retina. Let *O* be an object at a comparatively short distance such that Ac. (represented here by increase in curvature of the cornea) is necessary in order to retain the image on the retina. A ray Ay_1 drawn through the anterior focus F_1 of the accommodated eye, will proceed after refraction parallel to the principal axis and determine the size of the retinal image xy. Then $xy = x_1y_1$ its projection on to the refracting plane or cornea P. Let the distance of the object *from the cornea* be f_1; let f_2 be the posterior conjugate focus x_1x which is a fixed value, since the image is formed at the retina.

Now, in order that xy may remain on the retina the value of F_1 is found from—

$$\frac{1}{f_1}+\frac{\mu}{f_2}=\frac{1}{F_1} \qquad \text{whence } F_1=\frac{f_1f_2}{\mu f_1+f_2}$$

But μ and f_2 being, say, 4/3 and 20 respectively—

$$F_1=\frac{20f_1}{4f_1/3+20}=\frac{15f_1}{15+f_1}$$

But—

$$\frac{x_1y_1}{AB}=\frac{F_1x_1}{BF_1}=\frac{F_1}{f_1-F_1}$$

and by the substitution of the value of F_1 in the latter we have—

$$xy=\text{retinal image}=\frac{15\ O}{f_1}$$

where O is the size of the object.

This is strictly accurate for *all* values of f_1 *measured from the cornea*, and of course is identical with the approximate formula when the changes due to accommodative action disappear for great values of f_1. The similarity between the two formulæ otherwise depends upon the fact that 4/3 is taken as the mean index.

The size of the retinal image is probably under-estimated when the constant 15 is used. The latter changes with the original dimensions and if the values of the anterior and posterior principal foci are 16·5 and 22·25, μ still being 4/3 we have—

$$I=\frac{16{\cdot}5\ O}{f_1}$$

Thus suppose an object 5 cm. in size and 10 cm. from the cornea be clearly seen by an eye exerting 10 D. Ac. The true size of the retinal image, for an axial length of 24 mm. is—

$$\frac{16{\cdot}5\times 5}{10}=8{\cdot}35 \text{ mm.}$$

instead of 7·5 mm. as would be found if the constant 15 were used.

The approximate formula previously given would be inapplicable for an object at 10 cm. since the distance of the nodal point to the retina would, on the exertion of Ac., no longer be 15 mm. or 16·5 mm. as may be used.

The Retinal Image in Ametropia.—When there is Am., always presumed to be axial, the usual procedure is to employ the approximate calculation and substitute for the distance of nodal point to retina—15 or 16·5 as the case may be—the increased or decreased value in M. or H. respectively. Thus in M. or H. 3 D. we should add or deduct about 1 mm. from the mean constant employed and, of course, more or less in proportion as the Am. were higher or lower.

For example, what is the size of the retinal image in M. 6 D. and H. 6 D.? Here, taking 15 mm. as the mean value, the distance of nodal point to retina would be, say, 17 and 13 respectively so that the retinal image in the two cases would be, for an object 10 cm. high at 1 metre—

$$\frac{17 \times 10}{100} = 1{\cdot}7 \text{ mm.} \quad \text{and} \quad \frac{13 \times 10}{100} = 1{\cdot}3 \text{ mm.}$$

Such calculations are, however, of little utility. In M. the image would be extremely blurred unless the object were at the P. R. In H. with Ac. relaxed, it would be similarly blurred and if Ac. be used the optical system is entirely altered as it would be also for an accommodated M. eye with the object within the P. R.

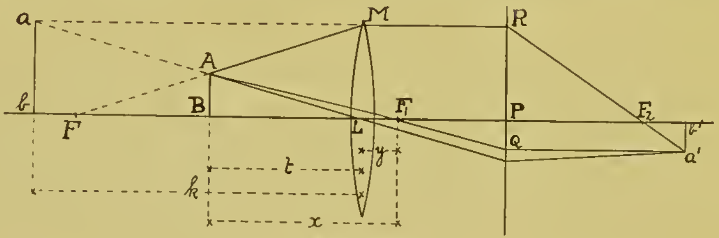


FIG. 137.

Ratio of the Sizes of Retinal Image and Object in Conjunction with a Lens.

To determine the relation between the size of the retinal image and that of the object, when a lens is interposed, is rather more complicated than with the eye alone. We have to determine the relation between the lens image and the object and then that between the lens image and the retinal image.

Fig. 137 which is very diagrammatic, is intended to illustrate the course of light from an object AB placed within F of a convex lens L to the retinal image $b'a'$. We have first to construct the virtual image ab formed by the lens alone and this is done by drawing (1) a ray AM diverging apparently from the focus F; this, after refraction, proceeds parallel to the axis towards the refracting plane P of the eye and is refracted at R to pass through the posterior principal focus F_2 (2) A ray AQ refracted by the lens to pass through F_1 proceeds, after refraction at Q, parallel to the principal axis and meets the ray RF_2 somewhere in a'. (3) A ray AL directed towards the optical centre of L would be transmitted to meet the ray RF_2 also in a'. The point a from which these rays appear to diverge is the image of A and similarly b is the image of B such that ab is the complete virtual image of AB due to the lens L. In turn $b'a'$ is the complete image of AB after indirect formation by the lens L. This construction also serves for a concave lens, the only difference being that the image ab is diminished instead of magnified.

Fig. 138, also diagrammatic, illustrates the formation of the image when AB is beyond F. The construction is too obvious to need any special description.

In Fig. 137, let O be the size of the object, I the size of the virtual image ab and I′ that of the retinal image $b'a'$. Then the ratio of $b'a'$ to AB, *i.e.* the *magnification*, is—

$$M = \frac{I'}{O}$$

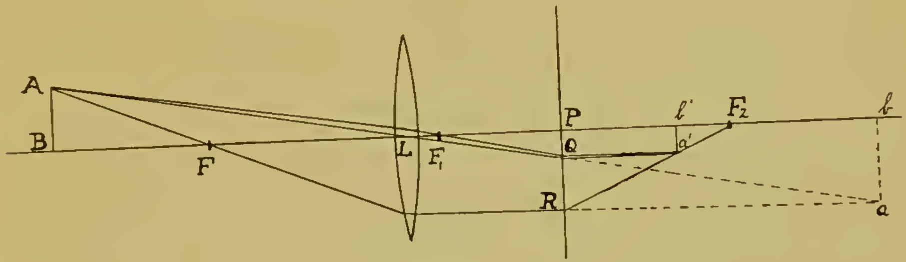


Fig. 138.

Let the distance BL of object to lens $= t$, and let the distances BF_1 and LF_1 be equal to x and y respectively, and $bL = k$. Then from similar triangles we have—

$$\frac{I'}{I} = \frac{PQ}{I} = \frac{PF_1}{bF_1} = \frac{F_1}{k+y} \quad \dots \quad \dots \quad \dots \quad \dots \quad (1)$$

and

$$\frac{I}{O} = \frac{bL}{BL} = \frac{k}{t}$$

Therefore the magnification of the retinal image is—

$$\frac{I'}{O} = \frac{kF_1}{t(k+y)} \quad \dots \quad \dots \quad \dots \quad \dots \quad \dots \quad (2)$$

But from ordinary conjugate foci—

$$\frac{1}{F} = \frac{1}{t} - \frac{1}{k}$$

whence

$$\frac{t}{k} = 1 - \frac{t}{F} = 1 - \frac{(x-y)}{F} = \frac{F - x + y}{F}$$

and the magnification from (2) is—

$$\frac{I'}{O}=\frac{FF_1}{(k+y)(F-x+y)} \qquad \dots \quad \dots \quad \dots \quad \dots \quad (3)$$

But

$$k=\frac{tF}{F-t}=\frac{F(x-y)}{F-x+y}$$

On substitution of this in (3) we have—

$$M=\frac{I'}{O}=\frac{FF_1}{Fx-xy+y^2}$$

The last expression gives the required ratio between the sizes of retinal image and object in terms of the distances of object and lens from the anterior focal point and also of the foci of eye and lens. This formula is valuable and if examined will present some curious points connected with the movement of lenses in front of the eye.

Firstly let $y=0$, *i.e.* let the lens be placed at the anterior focal point of the eye. Then—

$$M=\frac{FF_1}{Fx}=\frac{F_1}{x}$$

Now the ratio F_1/x is independent of the lens and therefore, whatever the power of the latter, it can have no effect on the size, but only on the *position*, of the image $b'a'$. In other words we have demonstrated mathematically the general rule given previously that the size of the retinal image is not affected by any lens that may be placed at the anterior focal point.

Suppose $x=y$; again we have—

$$M=\frac{F_1}{x}$$

That is, if $x=y$, the lens touches the object and therefore can have no influence whatever on the retinal image. There are, therefore, two positions of the lens in which the retinal image is independent of it—in the anterior focal plane and in the plane of the object.

The most curious fact, however, comes to light at a stage intermediate between these extremes. Taking the denominator of the formula we notice that at first, as y increases, $Fx-xy+y^2$ decreases and therefore the magnification increases but beyond a certain point the denominator starts to increase again and therefore the magnification diminishes. The minimum value of the denominator occurs when $y=x/2$ and therefore here also occurs the maximum magnification. If F be negative we find the reverse condition—magnification is a minimum when $y=x/2$.

We have, therefore, the rule that *the retinal image is of maximum size when a Cx. lens is midway between the object and anterior focus of the eye; it is a minimum when a concave lens is similarly placed.* If the experiment be tried with a convex lens, the object will apparently increase in size as the lens is withdrawn, reach the maximum at the midway point, and then diminish to its original size when the object and lens are coincident.

If the lens be concave, the image diminishes during the first part of the lens movement and when beyond the half-way point, increases to its original size as lens and object coincide. A displacement of the lens *towards* the cornea from F_1 must be reckoned negative, and then it will be found that the magnification decreases if the lens is convex, and increases if concave, compared with the magnification obtained at F_1. The above arguments do not, of course, apply when the convex lens is so strong that, on advancement, the real·image of the object is formed in front of the eye. On the other hand any power concave can be employed to demonstrate the variation in magnification since the image formed is always virtual.

It must also be particularly noticed that magnification is quite independent of the sharpness of the retinal image. Definition is dependent upon the divergence or convergence of the individual rays of a pencil whereas magnification or size of image is governed solely by the pencils as a whole, *i.e.* by the secondary axes. Thus, although the size of the image *always* increases as we first withdraw a convex lens, it does not follow that we also obtain an increase of effectivity. In other words, effectivity and definition are entirely independent of each other—an increase in the image does not always mean an increase in effectivity or *vice versa* and, generally, the one predominates to a marked degree. Thus presbyopes, by pulling their lenses down the nose may, or may not, obtain increased convex effect, but they invariably obtain larger retinal images.

CHAPTER XXI

OCULAR CALCULATIONS

Dioptrics and Constants of the Eye.

The Emmetropic Eye.—The average normal eye is supposed to be of certain length and size, to have surfaces of certain curvature, and media of certain refractive indices, as given in the following paragraphs. This average emmetropic eye is termed the *schematic eye;* while if, for the sake of simplicity, it is reduced to a single refracting body, as any compound refracting system may be, it is termed the *reduced eye.*

The figures and constants given to the schematic eye by various authorities differ somewhat, and those here given do not exactly agree with others; the main difference is in the length of the optic axis to which quantities varying between 22 and 25 mm. are given. To conform with these different lengths the chief variation is in the refractive index assigned to the crystalline. The curvatures of the cornea and crystalline, the thickness and position of the latter, and the refractive indices of the cornea, aqueous and vitreous seem to have constants pretty generally accepted.

By some the corneal radius is made shorter, about 7·7 mm., but this rather increases the difficulty unless, as is sometimes done, the refractive index is taken as higher than that of the aqueous, so that the concave posterior surface of the cornea may have its effect in increasing the focal length of the eye in order to conform with an increased axial length. It has not been thought worth while to further complicate the already sufficiently involved refracting system of the eye in this way. The figures in the first calculations are as *round* as could be selected without departing too far from those of recognized authorities on the subject; at the same time they give cardinal points which agree with those of the reduced eye used for ordinary calculations, and for this purpose are the more useful. It is, however, known that the average Em. eye is about 24 mm. long and this is the basis of the second calculated schematic eye, the figures pertaining to which are preferable when greater exactitude is required; they have therefore been used in calculations in this and other chapters.

In order that a perfect optical system may result, it is necessary that some changes be made in the figures taken for the one and the other. The curvatures of the surfaces must be lessened or the refractive index of the lens decreased, or that of the vitreous increased, for the longer eye. Now the surfaces given to the lens are generally accepted, and any increase of the corneal radius makes too great a departure from that which is known to be about correct. An altered value to the index of the vitreous would necessitate the same to the aqueous or it would be impossible to consider the crystalline as a lens having $F_1 = F_2$. If both were increased, lessened refraction would result, but the calculations would become more complicated since we could no longer regard the cornea and aqueous as one body.

Consequently the one factor that can be conveniently changed is that of the refractive index of the crystalline; indeed this is so estimated that the emmetropic eye may have its posterior principal focus at the retina. The crystalline actually is formed of a series of layers of varying density and curvature, both of which increase from cortex to nucleus; the radii of the external layers being taken as 10 mm. and 6 mm., it is necessary to compute a general refractive index, for the whole body, such that its focal length is the same as that caused by a series of surfaces of increasing power from the outside to the centre and whose power, when added to that of the cornea, causes the principal focus of the eye to be at the retina. In other words we must calculate an imaginary homogeneous lens having radii equal to those of the external crystalline layers, and a uniform index which, in conjunction with such radii, will give a power equal to the actual crystalline lens *in situ* between the aqueous and vitreous, both of whose indices have been previously determined.

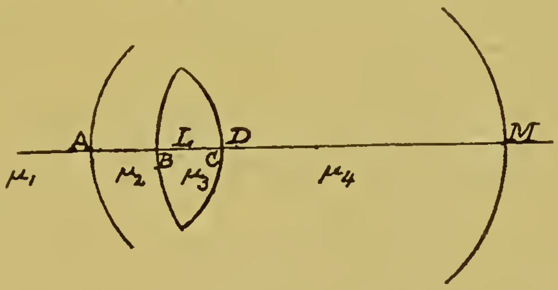


FIG. 139.—THE REFRACTING SURFACES AND MEDIA OF THE EYE.

The Optical System of the Eye.—The eye as an optical system consists of three refracting surfaces—*A*, *B*, and *C*—combined with a concave receiving surface *M*. The cardinal points (Fig. 139) are 6 in number, namely, 2 focal points, 2 principal points and 2 nodal points, and they can be found by calculation in which the second and third refracting surfaces *B* and *C* are taken as forming a double convex lens *L*, in conjunction with the single refracting surface *A*.

To calculate the cardinal points of the *schematic* eye, it is necessary—(1) to find these points for the first system—the cornea *A*; (2) to find these points for the second system—the lens *L*; (3) to combine the two systems *A* and *L*.

Schematic Eye No. 1 calculated for an axial length of 22·2 mm. and cardinal points which correspond with those of the *reduced* eye. The figures are as follows:—

The cornea *A* has a radius r_1 of 8 mm.

The front surface of the crystalline *B* a radius r_2 of 10 mm.

The back surface *C* a radius r_3 of 6 mm.

The distance *AB* from the cornea to the crystalline is 3·6 mm.

$BC = t$, the thickness of the crystalline, is also 3·6 mm.

μ_1, μ_2, μ_3, μ_4, the four media through which the light passes, have the following refractive indices: $\mu_1 = 1$, $\mu_2 = 1{\cdot}333$, $\mu_3 = 1{\cdot}450$, and $\mu_4 = 1{\cdot}333$.

FIG. 140.—THE OPTICAL SYSTEM OF THE CORNEA.

The Optics of the Cornea.—The anterior focal length of the cornea A (Fig. 140) is—

$$F_A = \frac{r_1\mu_1}{\mu_2 - \mu_1} = \frac{8 \times 1}{1{\cdot}333 - 1} = 24 \text{ mm.}$$

The posterior focal length is—

$$F_B = \frac{r_1\mu_2}{\mu_2 - \mu_1} = \frac{8 \times 1{\cdot}333}{1{\cdot}333 - 1} = 32 \text{ mm.}$$

The ratio—

$$\frac{F_A}{F_B} = \frac{24}{32} = \frac{1}{1{\cdot}333} = \frac{3}{4} = \frac{\mu_1}{\mu_2}$$

and $F_B - F_A = 32 - 24 = 8 =$ the radius of curvature.

The principal point is at the surface A; the nodal point is at D, the centre of curvature, which is 8 mm. behind A.

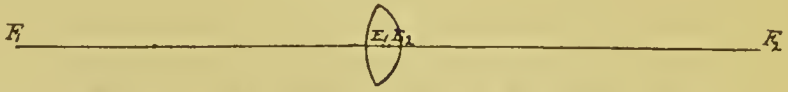


FIG. 141.—THE OPTICAL SYSTEM OF THE CRYSTALLINE.

The Optics of the Crystalline.—Being given a presumed refractive index of 1·450 and having similar media on both sides of $\mu = 1{\cdot}333$, the relative index μ_r of the crystalline lens is—

$$\mu_r = \frac{\mu_3}{\mu_2} = \frac{1{\cdot}450}{1{\cdot}333} = 1{\cdot}087.$$

Let the following quantity be called Q.

$$\left(r_2 + r_3 - t\,\frac{\mu_r - 1}{\mu_r}\right)$$

Then

$$Q = 10 + 6 - 3{\cdot}6 \times \frac{1{\cdot}087 - 1}{1{\cdot}087} = 15{\cdot}72.$$

The distance of the first equivalent point E_1 from the front surface B is—

$$E_1 = \frac{r_2\, t}{\mu_r\, Q} = \frac{10 \times 3{\cdot}6}{1{\cdot}087 \times 15{\cdot}72} = \frac{36}{17{\cdot}06} = 2{\cdot}1 \text{ mm.}$$

The distance of the second equivalent point E_2 from the back surface C is—

$$E_2 = \frac{r_3\, t}{\mu_r\, Q} = \frac{6 \times 3{\cdot}6}{1{\cdot}087 \times 15{\cdot}72} = \frac{21{\cdot}6}{17{\cdot}06} = 1{\cdot}26 \text{ mm.}$$

The anterior and posterior focal lengths are equal and are represented by F_C. Then—

$$F_C = \frac{r_2\, r_3}{(\mu_r - 1)\, Q} = \frac{10 \times 6}{0{\cdot}087 \times 15{\cdot}72} = \frac{60}{1{\cdot}368} = 43{\cdot}86 \text{ mm.}$$

In this case the anterior is equal to the posterior focal length because the first and last media have the same refractive index—that is, $\mu_2 = \mu_4$; also the principal points coincide with the nodal points and may therefore be termed the *equivalent points.*

The distance $E_1E_2 = T$ is the equivalent thickness of the lens and

$$T_C = 3{\cdot}6 - (2{\cdot}1 + 1{\cdot}26) = 3{\cdot}6 - 3{\cdot}36 = 0{\cdot}24 \text{ mm.}$$

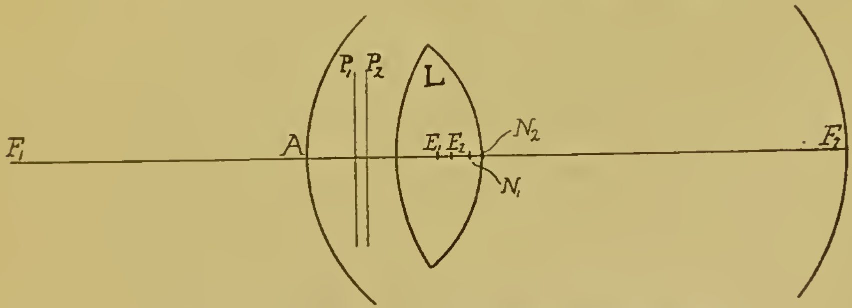


Fig. 142.—The Optical System of the Eye.

The Optics of the Schematic Eye No. 1.—Combining the two systems A and L (Fig. 142), the distance between the adjacent principal points of A and L $= d$, and—

$$d = AE_1 = 3{\cdot}6 + 2{\cdot}1 = 5{\cdot}7 \text{ mm.}$$

Let the quantity $F_B + F_C - d$ be called Q.

$$Q = 32 + 43{\cdot}86 - 5{\cdot}7 = 70{\cdot}16.$$

The distance of the first principal point P_1 behind the cornea is—

$$P_1 = \frac{F_A d}{Q} = \frac{24 \times 5{\cdot}7}{70{\cdot}16} = \frac{136{\cdot}8}{70{\cdot}16} = 1{\cdot}95 \text{ mm.}$$

The distance of the second principal point P_2 in front of E_2, the second equivalent point of the crystalline, is—

$$P_2 = \frac{F_C d}{Q} = \frac{43{\cdot}86 \times 5{\cdot}7}{70{\cdot}16} = \frac{250}{70{\cdot}16} = 3{\cdot}56 \text{ mm.}$$

Then P_2 lies behind the cornea at a distance—

$$AP_2 = 3{\cdot}6 + 3{\cdot}6 - (1{\cdot}26 + 3{\cdot}56) = 2{\cdot}38 \text{ mm.}$$

The anterior focal length F_1 of the eye is—

$$F_1 = \frac{F_A F_C}{Q} = \frac{24 \times 43{\cdot}86}{70{\cdot}16} = \frac{1052{\cdot}64}{70{\cdot}16} = 15 \text{ mm.}$$

The posterior focal distance F_2 is—

$$F_2 = \frac{F_B F_C}{Q} = \frac{32 \times 43{\cdot}86}{70{\cdot}16} = \frac{1403{\cdot}52}{70{\cdot}16} = 20 \text{ mm.}$$

The ratio—

$$\frac{F_1}{F_2} = \frac{15}{20} = \frac{1}{1{\cdot}333} = \frac{3}{4} = \frac{\mu_1}{\mu_4}$$

The radius of curvature of the ideal refracting surface is—

$$F_2 - F_1 = 20 - 15 = 5 \text{ mm.}$$

The distance T between the principal points is—

$$T = P_2 - P_1 = 2{\cdot}38 - 1{\cdot}95 = 0{\cdot}43 \text{ mm.}$$

The nodal points, N_1 and N_2, are located thus: the distance between N_1 and P_1 or N_2 and P_2 is equal to $F_2 - F_1 = 5$ mm.; so that—

$AN_1 = 1{\cdot}95 + 5 = 6{\cdot}95$ mm. $AN_2 = 2{\cdot}38 + 5 = 7{\cdot}38$ mm.

then also—

$$N_2 - N_1 = 7{\cdot}38 - 6{\cdot}95 = 0{\cdot}43 \text{ mm.}$$

Tabulated Positions of the Cardinal Points.

Distance from Cornea in mm.

$F_1 = 13{\cdot}05$	$P_1 = 1{\cdot}95$	$N_1 = 6{\cdot}95$
$F_2 = 22{\cdot}38$	$P_2 = 2{\cdot}38$	$N_2 = 7{\cdot}38$

F_1 is 15 mm. from P_1 and 20 mm. from N_1.
F_2 is 20 mm. from P_2 and 15 mm. from N_2.

Simplified Cardinal Points.

The interval between the two principal points is so small that they can be regarded as one, P; so also can the two nodal points be taken as one, N. Thus in the simplified schematic eye there are but four cardinal points, viz., two focal points, one principal and one nodal point.

The distance of F_1 from P and F_2 from N = 15 mm.
,, ,, F_2 from P and F_1 from N = 20 mm.
,, ,, P from the cornea = 2·2 mm.
,, ,, N from the cornea = 7·2 mm.
,, ,, N from P = 5 mm.
The length of the optic axis = 22·2 mm.
The anterior focal power D_A = 66·66 D.
The posterior focal power D_P = 50 D.

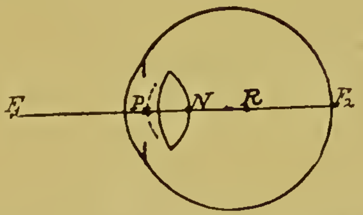


FIG. 143.—THE SCHEMATIC EYE. (Natural size.)

The Significance of the Principal and Nodal Points.—The principal point marks on the optic axis, the ideal refracting surface or the imaginary plane on which the refraction of the three surfaces of the eye is presumed to be united and from which the focal lengths are measured. The nodal point is that at which the secondary axes cut the principal axis—*i.e.* those rays which pass through the nodal point are not deviated, and the angle which an object subtends at the nodal point governs the size of the retinal image.

Schematic Eye No. 2 calculated for an axial length of 24 mm.

All the data are the same as in No. 1 with the exception that $\mu_3 = 1{\cdot}418$.

The *cornea* is as previously calculated. For the *crystalline* we get $\mu_r = 1{\cdot}418/1{\cdot}333 = 1{\cdot}0635$.

Having the same thickness and radii but with $\mu_r = 1{\cdot}0635$, by similar calculations we obtain $E_1 = 2{\cdot}15$ mm. $E_2 = 1{\cdot}28$ mm. $F_C = 60$ mm. $T_C = {\cdot}17$ mm.

Combining the two systems, the approximate values for the *eye* are—

$F_1 = 16{\cdot}7$ mm. $P_1 = 1{\cdot}6$ mm. $N_1 = 7{\cdot}16$ mm.
$F_2 = 22{\cdot}26$ mm. $P_2 = 1{\cdot}92$ mm $N_2 = 7{\cdot}48$ mm.
$T = {\cdot}32$ mm. $F_2 - F_1 = 5{\cdot}56$ mm.

Assuming the two principal points and the two nodal points to be each united, we may approximate the above figures to—

The distance of F_1 from P and F_2 from N $= 16{\cdot}5$ mm.
" " F_2 from P and F_1 from N $= 22{\cdot}25$ mm.
" " P from the cornea $= 1{\cdot}75$ mm.
" " N from the cornea $= 7{\cdot}5$ mm.
" " N from P $= 5{\cdot}75$ mm.
The length of the optic axis $= 24$ mm.
The anterior focal power D_A $= 60$ D.
The posterior focal power D_P $= 45$ D.

The Reduced Eye. = For convenience in calculations, the eye may be reduced to a single refracting body from which the crystalline is presumed to be absent, so that there is only one refracting surface and medium, *i.e.* the cornea, which is at the ideal refracting plane (the principal plane) of the schematic eye. It is given a radius of curvature suitably corresponding to this position, viz., 5 mm. which is the distance between the principal and nodal points of the schematic eye No. 1.

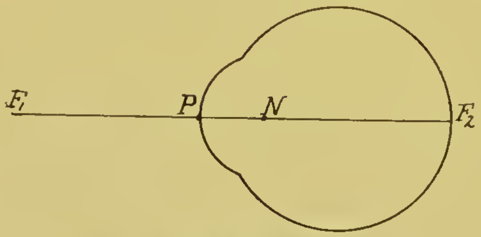


FIG. 144.—THE REDUCED EYE.

Constants and Calculations.—$\mu = 1{\cdot}333$, $r = 5$ mm.

$$F_1 = \frac{5}{1{\cdot}333 - 1} = 15 \text{ mm. in front of P.}$$

$$F_2 = \frac{5 \times 1{\cdot}333}{1{\cdot}333 - 1} = 20 \text{ mm. behind P.}$$

P is at the cornea. N is 5 mm. behind P.

The nodal point is at the centre of curvature of the cornea; the focal lengths, the positions of P and N and the distance between them are all the same in the reduced eye as in schematic eye No. 1. The two focal points, with the principal and nodal points, constitute the four cardinal points of the reduced eye.

If a reduced eye were calculated on the figures of system No. 2 we should have $r = 5{\cdot}5$ mm. and therefore $F_1 = 5{\cdot}5 \times 3 = 16{\cdot}5$ mm. and $F_2 = 5{\cdot}5 \times 4 = 22$ mm.; or if r be taken $= 6$ mm. we have F_1 and $F_2 = 18$ mm. and 24 mm. respectively.

OPTICAL CONSTANTS OF THE EYE.

	Calculated Eye No. 1.	Calculated Eye No. 2.
Cornea :		
Thickness	1 mm.	—
μ	1·333	—
Radius	8 mm.	—
Principal point at cornea	—	—
Nodal point behind it	8 mm.	—
Anterior focal length	24 ,,	—
Posterior focal length	32 ,,	—
Anterior focal power	42 D.	—
Posterior focal power	31 D.	—
μ of aqueous and vitreous	1·333	—
Crystalline :		
Thickness	3·6 mm	—
Computed μ	1·45	1·418
Relative μ	1·089	1·0635
Anterior radius	10 mm.	—
Posterior radius	6 ,,	—
First equivalent point	2·1 mm.	2·15 mm.
Second equivalent point	1·26 ,,	1·28 ,,
Focal length	43·86 ,,	60 ,,
Focal power	23 D.	16 D.
The Schematic Eye :		
Length of optic axis	22·2 mm.	24 mm.
Principal point	2·2 ,,	1·75 mm.
Nodal point	7·2 ,,	7·5 ,,
P. to N.	5 ,,	5·75 ,,
Anterior focal length	15 ,,	16·5 ,,
Posterior focal length	20 ,,	22·25 ,,
Anterior focal power	66·66 D.	60 D.
Posterior focal power	50 D.	45 D.
Cornea to front of crys.	3·6 mm.	—
Cornea to back of crys.	7·2 ,,	—
Cornea to centre of rotation	13·2 ,,	14 mm.
Nodal point to centre of rotation	6 ,,	6·5 ,,
Retina to centre of rotation	9 ,,	10 ,,

Where the figures of the two calculated eyes differ they are for comparison placed side by side.

The Combined Dioptric System of an Eye and Lens.

Let the lens be placed in the anterior focal plane or 16·5 mm. in front of the principal plane of the schematic eye No. 2. P is the principal and N the nodal point, F'_1 is the anterior and F'_2 the posterior focal length of the eye, and F is the focal length of the lens; d is the distance of the lens from P.

F_1 is the anterior and F_2 is the posterior focal length of the combined system; E_1 is the anterior and E_2 the posterior equivalent points from which F_1 and F_2 are respectively measured. Now $d = F'_1$ so that $F + F'_1 - d = F$

Then (Fig. 145)—

$$E_1 = \frac{Fd}{F} = d = 16{\cdot}5 \text{ mm. backwards from L}$$

$$E_2 = \frac{F_2'd}{F} = \frac{365}{F} \text{ outwards from P}$$

and—

$$F_1 = \frac{FF_1}{F} = F_1 = 16{\cdot}5 \text{ mm. from } E_1$$

$$F_2 = \frac{FF_2'}{F} = F_2 = 22{\cdot}25 \text{ mm. from } E_2$$

$$t = d - (E_1 + E_2) = -E_2$$

It will be seen that when the lens is placed in the anterior focal plane, F_1 and F_2 and E_1 are the same as if there were no lens and $E_2 = 365/F$ approx.—

$$N_1F_1 = F_2 = 22{\cdot}25 \qquad N_2F_2 = F_1 = 16{\cdot}5.$$

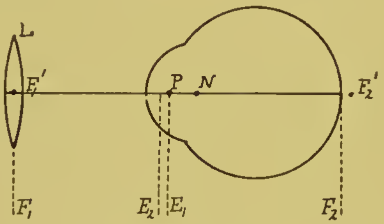


FIG. 145.

Thus if the lens L (Fig. 145) be, say, + 2·75 D. so that $F = 365$ mm. approx., we have $E_2 = 1$ mm. out from P and since E_2 coincides with P the two equivalent points are crossed to the extent of 1 mm. The distance 1 mm. which F_2 lies in front of F'_2 is equal to the shortening of the globe when the eye is H. to that extent which is corrected by a 2·75 D. lens placed in the anterior focal plane. In this case the size of the retinal image is not changed by the lens since the focal distances and the distances $N_1 F_1$ and $N_2 F_2$ are unaltered, the only change that does occur being the shifting of E_2 forward by the Cx. lens (or backwards by a Cc. of − 2·75 D. in M.) so that F_2 is at the retina.

If $d = F$ so that the distance of the lens is equal to its focal length, we have—

$$E_1 = \frac{F^2}{16{\cdot}5} \qquad E_2 = \frac{22{\cdot}25}{16{\cdot}5}F = 4/3 \text{ F (approx.)}$$

$$F_1 = F \qquad F_2 = \frac{22{\cdot}25}{16{\cdot}5}F = 4/3 \text{ F (approx.)}$$

so that if $F = 100$ mm. we get—

$$E_1 = 600 \text{ mm.} \qquad E_2 = 133{\cdot}33 \text{ mm.}$$

$$F_1 = 100 \text{ mm.} \qquad F_2 = 133{\cdot}33 \text{ mm.}$$

$$t = -633 \text{ mm.}$$

Light parallel in the air meets at 133·33 behind E_2 or at the principal plane of the eye. Light parallel in the vitreous meets at 100 mm. in front of E_1 or 500 mm. behind the lens. Light diverging from F meets at the retina. Light diverging from the retina meets at F. That is, the anterior focus of the lens and the posterior focus of the eye are conjugates.

If $d = F + F'_1$ the combination is afocal for parallel light.

The Dioptric Change in the Accommodated Eye.

The amount of Ac. or auxiliary dioptric power, required for seeing at any distance, is the *dioptral* difference between the posterior focal length of the eye and the back conjugate focus which results when an object is near. Now this latter distance is less remote, from the refracting plane of the eye, than would be the case if the dioptric system were a lens in air, whose focal length is the same as the posterior focal length of the eye. The relative values of the anterior and posterior powers of the eye are as 4 : 3 or as μ of the vitreous : μ of air; similarly a dioptric effect D expressed, as in air, becomes, in the eye, D/μ. Thus the dioptric change of the eye when accommodated is—

$$\text{Ac.} = \frac{D}{\mu}$$

where D is the dioptric distance of the object from the principal plane.

The foregoing applies to the dioptric change which takes place in the emmetropic eye when it is accommodated. If the eye is ametropic—

$$\text{Ac.} = \frac{D - R}{\mu}$$

where D is the dioptric distance of vision in air measured from the principal plane and R is the far point in diopters measured from the same place.

Place of Dioptric Change.—In the foregoing calculation the change is presumed to take place at the front surface of the crystalline, which is close to the principal plane of the eye; or the Ac. is presumed equal to the power of an added thin Cx. lens, of suitable μ, placed in the aqueous at the principal plane. In the case of the reduced eye this lens is presumed to be placed immediately *behind* the ideal cornea. Thus if the Ac. is expressed by the power of a lens in air in contact with the *reduced* cornea, its value is D, and if by a lens immediately behind the *reduced* cornea, by D/μ or 3 D/4. The total power of the eye accommodated for, say, 33 cm. is anteriorly $60 + 3 = 63$ D.; posteriorly $45 + 3/1{\cdot}333 = 47{\cdot}25$ D.

If the auxiliary lens were placed at the back surface of the crystalline, that is, at the nodal point of the schematic or reduced eye, it would need to be stronger than if placed in the principal plane. If we disregard the difference of the distance of the object from the principal and the nodal points, the power of the thin auxiliary lens, or the accommodative action, at the nodal point is $D\mu$. Thus suppose an object at 25 cm.; we say that the Ac. exerted is 4 D. The dioptric change in the eye at the principal plane would be $4 \times 3/4 = 3$ D.; if the dioptric change could be made at the nodal point it would be $4 \times 4/3 = 5{\cdot}33$ D.; if the change took place at some certain point in the crystalline it would be 4 D. For light diverging from 25 cm. a focus would be obtained at the retina of an emmetropic eye by the interposition of a thin Cx. lens of 4 D. in front of the cornea, of 3 D. in the principal plane, of 5·33 D. at the nodal point and of 4 D. in the crystalline somewhere—approximately midway—between the principal and nodal points. The retinal image would, however, vary in size for the different positions of this *accommodating* lens.

When the eye is accommodated for about 14 cm. the crystalline may be considered to be practically an equiconvex lens, both surfaces being of 6 mm. radius. The anterior focal point of the eye then lies something over 1 mm. nearer to the cornea.

Principal and Nodal Points.—When the eye is accommodated all the values of the crystalline and of the eye become changed; in particular the interval between the principal and nodal points becomes lessened; the principal points recede from the cornea while the nodal points advance, but the differences are so small that they may be ignored.

Changes for the Amp. of Ac.—When the Amp. of Ac. is expressed by P − R in diopters, the value is represented by the power of a lens in air. The dioptric change which takes place in the eye is—

$$\text{Amp. Ac.} = \frac{P - R}{\mu}.$$

The value of P − R represented by an auxiliary lens placed at the nodal point is—

$$\text{Amp. Ac.} = (P - R)\mu.$$

Conjugate Foci of the Eye.

Conjugate foci, with respect to the eye, are calculated very simply because extreme accuracy is not needed. Thus when calculating the distance of the anterior conjugate if, say, 3 D. Ac. is exerted by an Em., we say that it is $100/3 = 33$ Cm. In this we take it that the increased power of the eye is equal to that which would be produced by the addition of a + 3 D. lens in the principal plane of the eye. Similarly we calculate the P. R. to be at 33 cm. positive or negative in, respectively, M. 3 D. and H. 3 D. Here we take it that the eye is increased or decreased in power, respectively, to the extent of 3 D., or, what is the same, the eye is longer or shorter to an extent equal to the difference between the length of a normal eye and that of an eye whose principal focus would be at the retina if the refracting power of the eye were reduced, or increased, to an extent represented by a 3 D. lens placed in the principal plane.

For accurate calculations it would be necessary to use the formulæ connecting the linear conjugates with the anterior and posterior principal foci of a single refracting surface, *i.e.*—

$$\frac{F_1}{f_1}+\frac{F_2}{f_2}=1 \qquad \text{or} \qquad F_1F_2=AB$$

where F_1 and F_2 are, respectively, the anterior and posterior focal distances and f_1 and f_2 the object and image conjugates; A and B are the distances of f_1 and f_2 respectively from F_1 and F_2.

If we wish to use dioptric expressions we have—

$$D_1\mu_1+D_2\mu_2=D_A \qquad \text{or} \qquad \frac{D_1}{\mu_2}+\frac{D}{\mu_1}=D_P$$

where D_A and D_P are respectively the anterior and posterior dioptric powers; D_1 and D_2 the anterior and posterior dioptric conjugates, and μ_1 and μ_2 the refractive indices of air and of the eye (reduced) in which D_1 and D_2 are respectively situated.

We have taken for the eye the values $F_1=16{\cdot}5$ mm. and $F_2=22{\cdot}25$ mm.; therefore $D_A=60$ and $D_P=45$. $\mu_1=1$ may be ignored and $\mu_2=1{\cdot}333$ may be taken as 4/3.

$$F_1\mu_2=F_2 \qquad \text{and} \qquad D_P\mu_2=D_A$$

Now—

$$D_1+4\ D_2/3=D_A=60 \qquad \text{or} \qquad 3\ D_1/4+D_2=D_P=45$$

whence

$$D_1=60-4\ D_2/3 \qquad \text{or} \qquad 4/3\ (45-D_2)$$
$$D_2=3/4\ (60-D_1) \qquad \text{or} \qquad 45-3/4\ D_1$$

As an example, suppose an eye to be longer than the normal to the extent of 1·14 mm. so that the distance to the principal plane is $22{\cdot}25+1{\cdot}14=23{\cdot}39$ mm.

Then—

$$D_2=\frac{1000}{23{\cdot}39}=42{\cdot}75\ \text{D}$$

and—

$$D_1=60-4/3\times 42{\cdot}75=3\ \text{D}$$

That is to say, the conjugate focus of the retina is +3 D., or the P. R. is 3 D. positive (33 cm. in front of the eye), or the refractive condition is that of M. 3 D.

Suppose an object were at 1 m. in front of the eye; how far would the image be behind the refracting plane? We have—

$$D_2=\tfrac{3}{4}\ (60-1)=44{\cdot}25\ \text{D} \qquad \text{and} \qquad \frac{1000}{44{\cdot}25}=22{\cdot}6\ \text{mm.}$$

so that—

$$f_2=22{\cdot}6-22{\cdot}25={\cdot}35\ \text{mm. behind the retina.}$$

The Real Degree of Am.—We speak of nominal H. or M., as represented by the correcting lens placed in the anterior focal plane or 16·5 mm. in front of the refracting plane of the eye; and we then refer to the true degree of error as represented by a lens placed in the refracting plane, or in contact with the cornea of the reduced eye. The true degree of Am. does not, however, represent the actual posterior dioptric excess or deficiency. From the formulæ connecting the anterior and posterior focal powers of a single surface with its dioptric conjugates we have—

$$D_2 = \frac{D_A - D_1}{\mu_2} \qquad \text{or} \qquad D_2 = D_P - \frac{D_1}{\mu_2}$$

Suppose M. 1 D. where the P. R. is 1000 mm. = 1 D. from the refracting plane; then—

$$D_2 = \frac{60 - 1}{1{\cdot}333} \qquad \text{or} \qquad 45 - \frac{1}{1{\cdot}333} = 44{\cdot}25$$

and in H. 1 D. where the P. R. is − 1000 mm. = − 1 D. from the refracting plane, we get—

$$D_2 = \frac{60 + 1}{1{\cdot}333} \qquad \text{or} \qquad 45 + \frac{1{\cdot}333}{1} = 45{\cdot}75$$

Now the posterior conjugate of the Em. eye behind the principal plane is 45 D.; consequently we have, in M. 1 D., a conjugate deficiency, or increased length, and in H. a conjugate excess, or decreased length, of ·75 D. instead of 1 D. Expressing this as a formula we have the dioptric excess or deficiency in the eye $= D/\mu$. Indeed it may be said that any dioptric quantity D outside the eye becomes D/μ inside the reduced eye.

The Length of the Globe in Ametropia.

The P. R. and Length of Globe.—The formula for conjugate foci of a single surface is—

$$\frac{F_1}{f_1} + \frac{F_2}{f_2} = 1.$$

If for f_1 we put R, the distance of the far point from the principal point, and for f_2 we put L to represent the distance of the retina from the principal point, we have, using the simplified figures of the schematic eye No. 2—

$$\frac{16{\cdot}5}{R} + \frac{22{\cdot}25}{L} = 1$$

whence we get—

$$\frac{22{\cdot}25\ R}{R - 16{\cdot}5} = L \qquad \text{and} \qquad \frac{16{\cdot}5\ L}{L - 22{\cdot}25} = R$$

If R and L are expressed in diopters we have—

$$R + L\mu_2 = D_A$$

whence
$$\frac{3\,(60 - R)}{4} = L$$

or
$$\frac{4000}{3\,(60 - R)} = L \text{ in mm.}$$

Thus an eye which is myopic 1 D. has—
$$L = \frac{4000}{3 \times (60 - 1)} = 22{\cdot}6 \text{ mm.}$$

If an eye is hyperopic 1 D. then—
$$L = \frac{4000}{3 \times (60 + 1)} = 21{\cdot}85 \text{ mm.}$$

The increase or decrease of length b is the difference between the *exact* value of L, i.e., 22·2 mm., and F_2. The increase is greater in M. than is the decrease of length in H. of same degree although the difference is small for low errors. Finally the lengths, above given, are from P to the retina; for those of the eye there must be added 1·8 mm.

Variations in Length for True Am.—If the decrease or increase of length is known, we can learn the degree of true H. and M. respectively from—

$$\frac{2{\cdot}7\,b}{1 + {\cdot}045\,b} = \text{D. of H.} \qquad \frac{2{\cdot}7\,b}{1 - {\cdot}045\,b} = \text{D. of M.}$$

If the true degree of H. or M. is known we find—

$$\frac{D}{2{\cdot}7 + {\cdot}045\,D} = \text{decrease in H.} \qquad \frac{D}{2{\cdot}7 - {\cdot}045\,D.} = \text{increase in M.}$$

Thus suppose H. 10 D.; there is—
$$\frac{10}{2{\cdot}7 + ({\cdot}045 \times 10)} = \frac{10}{3{\cdot}15} = 3{\cdot}17 \text{ mm. decrease.}$$

And in M. 10 D. there is—
$$\frac{10}{2{\cdot}7 - ({\cdot}045 \times 10)} = \frac{10}{2{\cdot}25} = 4{\cdot}44 \text{ mm. increase.}$$

If the calculation had been made according to the power of the correcting lens 16·5 mm. in front of the refracting plane of the eye, it would be + 8·5 D. and − 12 D., respectively, and the result of the calculations would be the same as shown in the next article.

Variation in Length for Nominal Am.—When the degree of Am. is nominal, *i.e.* that represented by the correcting lens, the increase or decrease of length is best calculated by the formula—

$$AB = F_1F_2$$

A, which we will here call R, is the distance of the one conjugate beyond F_1 and therefore from the correcting lens, whose position closely coincides with F_1; it is the far point measured from the lens. B is the distance of the other conjugate beyond F_2 and therefore is the increase or decrease of length of the globe, which we will call b. Then—

$$Rb = F_1F_2 = 22\cdot25 \times 16\cdot5 = 367\cdot125$$

Hence we can learn the value of b or R, from the following formulæ, where the constant 365 is substituted for 367·125 :—

$$\frac{365}{R} = b \quad \text{and} \quad \frac{365}{b} = R$$

If R is positive, so also is b—the eye is too long; if R is negative, so also is b—the eye is too short. If the correcting lens is expressed in diopters we have—

$$\cdot365\ D = b \quad \text{and} \quad 2\cdot75\ b = D$$

Here, of course, b is positive or negative according as D. is negative or positive respectively.

It will be noticed that the values of b, for given errors, differ somewhat from those generally tabulated. Since, however, the method of calculation is not usually stated, there is some doubt as to whether the errors referred to are *true* errors, or those represented by the correcting lenses. Donder's formula is based on F_1F_2 of the reduced eye, which is $15 \times 20 = 300$.

The lengthening of the eye in M. is the same as the shortening in H. *both being represented by the correcting lenses;* but the + lens corrects more H. and the – lens less M. than its number indicates, *i.e.* a given lengthening pertains to less M. and the same amount of shortening to more H. or, in other words, as shown previously, M. causes a greater increase in length than the shortening in a similar degree of H. In comparing the two sets of formulæ, the above points must not be forgotten. For instance, suppose the errors are corrected, respectively, by a + 10 D. and a – 10 D. lens. 10 D. nominal H. is produced by a shortening of the globe of $\cdot365 \times 10 = 3\cdot65$ mm. The lens being 16·5 mm. in advance of the principal point, the true P. R. is $100 - 16\cdot5 = 83\cdot5$ mm., so that the length of the axis of the eye is—

$$\frac{22\cdot25 \times (-83\cdot5)}{-83\cdot5 - 16\cdot5} = 18\cdot6 \text{ mm.}$$

i.e. the eye is $22\cdot25 - 18\cdot6 = 3\cdot65$ mm. too short, and this shortening represents $1000/83\cdot5 = 12$ D. true H. approx.

The nominal M. of 10 D. is produced by a lengthening of the globe of $\cdot365 \times 10 = 3\cdot65$ mm. The lens being 16·5 mm. in advance of the principal point, the true P. R. is $100 + 16\cdot5 = 116\cdot5$ mm. so that the length of the axis of the eye is—

$$\frac{22\cdot25 \times 116\cdot5}{116\cdot5 - 16\cdot5} = 25\cdot9 \text{ mm.,}$$

i.e. the eye is $25\cdot9 - 22\cdot25 = 3\cdot65$ mm. too long and this lengthening represents $1000/116\cdot5 = 8\cdot5$ D. true M. approx.

Table of the Values of *b*.—Since refractionists are not very interested in the true error, there is given, in the following table, the approximate decrease in H., and the increase of length in M., for the errors as *represented by the correcting lens* placed about 15 mm. in front of the cornea.

Error in D.'s ..	1	2	3	4	5	6	7	8	9	10	12	14	16	18	20
Value of *b* in mm.	·365	·75	1·1	1·5	1·85	2·2	2·6	3	3·3	3·7	4·4	5·2	6	6·6	7·5

To obtain the length of the eye, the above figures must be deducted from, or added to 24 mm. in H. and M. respectively.

From this table we see that an eye corrected by a − 20 D. lens is, $24 + 7{\cdot}5 = 31{\cdot}5$ mm. in length, or nearly equal to the posterior focal length of the cornea. Thus if the crystalline be extracted from such an eye, it becomes practically Em.

In all the foregoing calculations, the constants and figures employed are true only to a fair approximation. Exact constants are not necessary since we do not know the actual dimensions and curves of emmetropic and ametropic eyes.

Retinal Disc of Confusion.

Circular Disc.—In Em. the retinal image of a point is a point; in Am. it is a disc of confusion of definite size determined by the following formula, which holds good for both M. and absolute H. Ordinarily it is circular, because the pupil itself being circular, a section of a cone of light from a point corresponds to it in shape.

Let *b* be the increase, or decrease, of length of globe from which the Am. arises; it is also the distance of the retina from F_2, the posterior focus of the eye, and of the confusion disc B from the focal point. The size of the confusion disc is greater as the Am. is greater and *vice versa;* also it varies directly with the size *p* of the pupil. Its size is found from—

$$B = \frac{pb}{F_2}$$

We can give a value to *p* of 3·7 mm., which is a fair average size of the pupil; also $F_2 = 22{\cdot}25$ mm. and $b = {\cdot}365$ D., where D is the optical error represented by the power of the lens, placed at F_1 of the eye, which would correct it. Substituting the known values we have, for the diameter of the confusion disc—

$$B = \frac{3{\cdot}7 \times {\cdot}365}{22{\cdot}25} = {\cdot}06 \text{ D.}$$

?

The linear dimension of the confusion disc is ·06 mm. for 1 D. of error. Thus in M. 3 D., or absolute H. 3 D., the confusion disc is ·06 × 3 or ·18 mm.

If we take a retinal cone to measure ·0025 mm. we have for n, the number of cones covered linearly :—

$$n = 24 \text{ for 1 D. of error}$$

and the whole disc, whose radius is 12 cones, superficially covers—

$$\pi r^2 = \frac{22}{7} \times 12^2 = 450 \text{ approx.}$$

Roughly the number of cones covered linearly is 24 D and superficially 450 D^2, where D numerically represents the diopters of ametropia. The circles of confusion overlap, and the borders of the whole image is extended a distance equal to B/2 in every direction.

The relation of the size of B, the ocular confusion disc, to p, the size of the lens aperture, determines the point in the disc through which any ray passes after refraction.

Let g be the distance, from the optic axis of the eye, of the ray before refraction, and let h be its distance from the centre of the confusion disc; then $h = g \times B/p$.

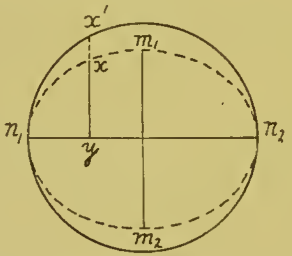


Fig. 146.

Astigmatic Disc.—If the refraction of the eye is astigmatic, let F′ and F″ be the two focal lines and p the pupil; then E the disc of confusion at any distance c from the refracting plane, is an ellipse whose axes are m_1m_2 and n_1n_2; let m and n be the lengths of these axes; then—

$$m = \frac{p\,(F' \sim c)}{F'} \qquad n = \frac{p\,(F'' \sim c)}{F''}$$

If m and n be known, E can be constructed; any point x on its periphery (Fig. 146) is distant xy from n_1n_2, and $\frac{xy}{x'y} = \frac{m}{n}$. Thus let $n = 3$, $m = 2$ and $x'y = 1$; then $xy = \frac{1 \times 2}{3} = \cdot 66$.

A ray of light incident on the principal plane of the eye, at a certain distance from the axes of the two principal meridians, passes through the elliptic confusion disc at distances, from its two axes, which are in the ratio n/p and m/p. Let g be the distance of the ray from the axis of the eye, corresponding to m_1m_2, and g' that from the axis, corresponding to n_1n_2; let h be its distance in the confusion disc from m_1m_2 and h' its distance from n_1n_2. Then—

$$h = g \times n/p \text{ and } h' = g' \times m/p.$$

CHAPTER XXII

FRAMES AND LENSES

Frame Fitting.

Frame fitting is an important part of the optician's work, for if it is not properly carried out the lenses fail to be as beneficial as they should be, and besides being uncomfortable or unsightly, they may even have undesirable optical effects.

A correctly adapted frame will (*a*) hold the lenses in the position required, (*b*) be comfortable, (*c*) have a good appearance, and (*d*) serve for a reasonable time. Comfort results not only from absence of inconvenience or pain, but also from the satisfaction derived from wearing what is appropriate and secure; even a pince-nez should maintain its position in all ordinary circumstances.

Frame fitting involves consideration of (*a*) the age and needs of the wearer, (*b*) the cosmetic effect and (*c*) the chief use to which the lenses are to be applied.

Asymmetry.—Eyes symmetrically placed are equidistant from the centre of the nose, and the distance between the inner canthi is approximately equal to either palpebral aperture.

The two sides of a face are, however, never exactly alike; the eyes are frequently not in exact alignment and it is said that this occurs in two out of every five people. The nose also is not in the exact centre of the face, but is usually nearer to the left eye—that is, the right eye is farther from the right side of the nose than is the left eye from the left side. As a rule, the two sides of the nose have not the same slope, and the one ear is often higher than the other, the right being generally the more elevated. These peculiarities are more marked when the two eyes of a person are of slightly different sizes and especially when there is antimetropia.

Slight differences in the height of the eyes, and their distances from the centre of the nose, may be ignored to a great extent, especially with lenses of low power, but it is better to consider rather the location of the stronger of two different lenses. If the latter are equal the higher eye, in the one case, and the one farther out, in the other, should be given first consideration.

Effects Due to the Lenses.—If lenses are too far away from the eyes, their effectivity is changed, and the retinal image not of the ideal size. If glasses for close work are not angled downwards, the lines of vision are oblique to the axes of the lenses when the eyes are lowered for reading; in the latter case, owing to convergence, the lenses are always slightly oblique in the horizontal plane, the remedy of inclining the lenses outwards at the temporal ends not being generally adopted.

Effects Due to Rotation of the Eyes.—The optical axes of lenses should coincide with the visual axes in their primary position, but when rotation to a secondary position occurs there is introduced a prismatic effect, due to decentration, and a cylindrical effect, due to obliquity, of the visual lines. The prismatic effect increases with the distance of the lenses from the eyes, so this distance should be as small as possible. Both effects are greater as the lenses are stronger, and the deviation of the visual lines larger.

It is true that this decentring is "harmonious" if the lenses are of equal power, since they act with similar prismatic effect, up or down, as the two eyes are rotated in a vertical plane, or as the eyes are rotated to the right or left; the one acts as a prism base in, and the other as a prism base out. This is not, however, the case if the lenses are of unequal or dissimilar powers, nor is it the case when convergence occurs. Cx. lenses cause increased, and Cc. lenses decreased, convergence on rotation of the visual lines inwards from the axes of the lenses.

General Consideration.—It is impossible to fulfil perfectly every requisite as to the position of the glasses, for various positions of the eyes. If the lenses are perpendicular to the lines of vision when looking straight forward, they must be oblique to it during reading. If they be exactly centred for distance, they must be decentred outwards for close work. Frame fitting must be a matter of compromise, the position in which the glasses are mostly used being chiefly regarded. The various effects produced by oblique, or vertically decentred, lenses are discussed elsewhere in this book.

The eyes are more often regarding near than distant objects, and they are more frequently observing objects situated below their level than those above, or even on a line with them; they are directed downwards when walking or driving, reading, writing or during almost any near work involving the hands. The eyes are, also, more frequently converged than not, especially in city life; the feet and hands are well within the convergence region, as is the tool, the book, the pen, the music, or the whatnot of one's daily occupation. Even distance glasses (others being specially provided for reading) are used not only for vision of objects beyond 6 m., and on a level with the eyes, but also, and more generally, for those that are nearer and lower. Therefore lenses exactly centred, for the primary position of the visual lines, may be troublesome to the wearer since, on looking downwards without lowering the head, he is apt to encounter the lower eye-wires.

With the frame needed for constant use the horizontal adjustment is as for distance rather than for close work because, when the eyes are converged for near vision, there is a slight prismatic effect base out with Cx. and base in with Cc. lenses. This is usually more desirable than the opposite condition, but may be contra-indicated by the muscular condition present.

When looking downwards, Cx. lenses set well down act as prisms base down and so relieve the inferior recti. Cc. lenses have a reverse effect and should not be lowered to so great an extent. In all frame adjustments it is desirable to avoid throwing strain on inefficient horizontal muscles, and still more on vertical. Also with respect to the vertical centring, it is better to have both lenses acting as prisms base up or base down, than the one up and the other down; this should be looked for in anisometropia and unequal height of the two eyes. In this chapter it is taken that the visual axes coincide with the centres of the pupils.

Lenses may be required for (*a*) distance only, (*b*) constant use, or (*c*) near work only. There are four conditions to consider, viz. (1) Interpupillary distance, (2) Height, (3) Angle, (4) Projection.

A spectacle frame for *distance only* should have a **W** bridge and curl sides, which keep the lenses in a fixed position in front of the eyes.

(1) The optical centres of the lenses must be opposite to the centres of the pupils when the eyes are directed to a distant point; this governs the P. D.

(2) The point observed should be on the ground about 12 m. distant or half-way to the ground at 6 m.; this governs the height.

(3) The lenses must be perpendicular to the lines of vision, that is, practically parallel to the plane of the irides; this governs the angle.

(4) The lenses must be as near to the eyes as the lashes permit; this governs projection.

A frame for *constant use* should have Nos. 1, 3, and 4 the same as for distance; No. 2 should be a little less, say, 1·5 mm.; *i.e.* the centres of the lenses should be in line with the bottoms of ordinary sized pupils when the eyes are directed as above. Constant use includes, of course, all close work.

A frame for *close work* only, as required in presbyopia, should have a **C** bridge and straight sides, which allow of the lenses being moved to and fro in front of the eyes.

(1) The lenses must be centred horizontally when the eyes are directed towards the face of the observer—that is, converged for about 40 cm. distance.

(2) The centres must be vertically adjusted so as to be in line with the bottom of the irides when the eyes are as above directed.

(3) The lenses should be inclined forwards above, about 10° from the plane of the irides.

(4) The Proj. need not be specially considered, 3 mm. being generally suitable.

Compared with distance, the P. D. is about 3 mm. less, and the Ht. about 3 mm. greater for close work only.

Methods of Frame Fitting.—Some opticians measure the face for the frame and this is the most accurate, although also the most difficult method; face measuring apparatus usually proves unsatisfactory, and a rule is commonly employed for the purpose. Others employ a set of numbered model frames, and the measurements of the one that suits are those of the frame required; in some cases the various requisite dimensions can be obtained only from different model frames; this is an easier method than the first-mentioned. Or, again, in ordinary cases the frame can be selected from stock, and this fitted with the lenses needed; this is the easiest and cheapest method, and the best suited to the everyday work of the average optician.

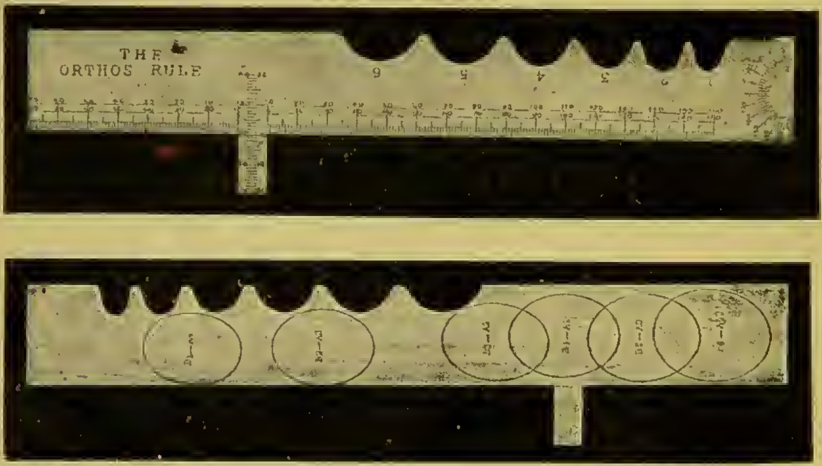


Fig. 147.—The "Orthops" Rule.

Face Measurements with the "Orthops" Rule.—In the interpretation of the following notes it is necessary to remember that right and left of the rule are, respectively, to the right and left of the optician; but right and left of the face, or frame measured, are, respectively, to the optician's opposite hand.

There are two horizontal scales on the rule; the lower scale has its zero at the right side of the projection, and is used chiefly for face measurements; the upper scale has its zero to the left of the projection, and serves mainly for frame measurements. There are also two vertical scales, the one having its zero at the end of the projection, and the other in the middle reading thence upwards and downwards.

To obtain true face measurements it is essential that the observed and the observer's eyes be on the same level, so that if the customer is seated the optician should be also.

Face Measurements.

P. D. for Distance and Constant Wear.—The client looks straight into the optician's left eye, the rule is held horizontally with the projection pointing downwards, and its right edge bisecting the right pupil; then the client is directed to look into the optician's right eye and the P. D. is read, on the lower scale, at the centre of the left pupil. Or, alternatively, the distance on the lower scale to the centre of the nose is read, and this doubled gives the P. D. If there is asymmetry of the face, such that the nose is nearer the one eye, the distance of each is read separately to the centre of the nose, in the manner indicated.

Some prefer to measure from, say, the left edge of the one pupil to the left of the other, but error would arise if the one pupil were smaller than the other, or if, as may occur, dilatation or contraction took place during the process of measurement.

P. D. for Presbyopia.—The client looks, with both eyes, at the centre of the optician's face, and the rule is placed, and the reading taken, as for distance.

Height of Bridge.—The client looking forward, the rule is placed horizontally, with the lower edge resting on the bridge of the nose, and the height is read downwards on the projection—to the centre of the pupil, for distance only—to the bottom of the pupil, for constant wear—to the bottom of the iris, for presbyopia. For unequal heights of the two eyes, the distance is read for each separately as shown. If the bridge of the nose is below the central line the rule is held horizontally with its lower edge bisecting the pupils or otherwise as may be needed, then with the projection at the right side of the nose, the distance is read downwards on it to a point level with the bridge of the nose.

Projection of Bridge.—The optician stands to the left of the client's head; the rule is held horizontally, with the lower edge resting against the bridge of the nose, and with the projection pointing backwards towards the left temple; the distance is read on the projection to a point level with the tips of the lashes. If the bridge of the nose is very receding, so that the spectacle bridge needs to be inset, the rule is placed with the end of the projection against the bridge of the nose, and the distance is read on the projection outwards to a point level with the tips of the lashes.

Depth of Bridge.—The rule is held with its edge at right angles to the bridge of nose, so that the projection inclines obliquely backwards at the side. The end of the projection being placed at the point where the shank should reach, the depth is read on the projection to the bridge of nose.

Width of Bridge.—The rule is held horizontally with the right edge of the projection pointing downwards at the right side of the nose, and the distance on the lower scale is read to the middle of the nose—this distance being doubled gives the width. Or, alternatively, the size of the bridge is determined by one of the standard spreads cut in the rule.

Facial Width.—The rule is held horizontally with the projection pointing backwards near the left temple, and the distance is read on the upper scale to the middle of nose—this distance being doubled gives the facial width; or alternatively the distance is read to a corresponding point at the right temple.

Length of Side.—The projection is placed at the back of the right ear, and the distance on the lower scale is read to a point level with the tips of the eyelashes; this gives the length to the curl, for a curled side. For a straight side, the edge of the projection is placed at the side of the head where the extremity of the spectacle side would be, and the distance is read as in the former case.

Spectacles.—The details of a spectacle frame are :—

1. P. D., or interpupillary distance.
2. Ht, or height of bridge.
3. Proj., or projection of bridge.
4. Depth of bridge.
5. Spread, or width of bridge.
6. Facial width.
7. Length of sides.
8. Angle of sides.
9. Size of eye.

Of the above only Nos. 1, 2, 3, 5 and 9 are really essential for a **W** bridge frame, and Nos. 1, 2 and 9 for a **C** bridge. The others are usually proportional to those mentioned, and need be given only in exceptional cases.

The P. D. of a Frame is the distance between the outer extremity of the one eye-wire to the inner extremity of the other, *i.e.* one entire eye-wire and the space between the two. On the face the P. D. is the distance between the centres of the pupils when the eyes are directed to ∞, *i.e.* in their primary position, but the crest of the nose is generally not exactly midway between the two eyes, so that a frame is slightly decentred *in* for the one and *out* for the other eye when its P. D. is the same as that of the face. Usually the decentration is so small that the ordinary spectacle serves, but if the difference be very marked, as it is in some cases, and the lenses strong, a frame specially made, or at least specially adapted, is required. The P. D. of a saddle bridge can be made greater or smaller, respectively, by increasing or decreasing the angle of the spur. Decrease is easier than increase and therefore if a frame be selected which is centred for the more distant eye, the other eye-wire can be brought nearer the centre. The bridge is not altered by this manipulation.

The average adult P. D. is 63 mm. for distance and about 3 mm. less for reading; the extremes, for ordinary faces, may be taken as 57 to 69 mm. but a small child may have a P. D. of, say, 50 mm. and an occasionally very wide one is met with.

The Ht. of Bridge of a frame is the vertical distance between the horizontal line bisecting the joints and the middle of the highest part of the bearing surface or crest of the bridge. On the face the Ht. is the distance between the crest of the nose, where the bridge lies, and the plane of the visual lines when the frame is in use. The average Ht. is, say, 3 to 6 mm. for distance and 6 to 9 mm. for presbyopic use. It is rarely below zero in Europeans.

A Crank or **C** bridge for presbyopic use must be high enough to allow of looking over the tops of the glasses at distant objects. A high **C** bridge acts in a similar manner to depth in a saddle or **W** bridge; it prevents rocking by its contact with the sides of the nose.

The Proj. of Bridge in a frame is the distance between the plane of the back of the eye-wires and the centre of the bridge crest. On the face the Proj. is the distance, outwards or inwards, of the crest of the nose from the tips of the lashes. If the nose is prominent, the lenses require setting *in;* if the nose is flat, or the lashes long, or the eyes prominent, the lenses must be set *out* to escape contact with the lashes. In all cases, for constant use, the lenses must be as near to the eyes as possible, the ideal position being about 15 mm. from the cornea, in the anterior focal plane, so that the retinal image may be as in Em.

The average Proj. is about 3 mm.; it may be greater or less and occasionally is negative, or backwards, for children and those with flat noses, or very projecting lashes. **C** bridges are usually made 3 mm. out, but the projection here is of little importance since the lenses are generally employed farther out from the eyes, at about 25 mm.

The Spread of Bridge is the distance between the backmost points of the bearing surface of the bridge, which is in contact with the nose; on the face the spread is the greatest width of the nose in contact with the bridge. The average base width is about 18 mm.

The bridge must be wide enough not to impress the nose at the sides, but not so wide as to permit rocking of the frame. A clean fit of a saddle bridge prevents the frame from sliding forward, and so removes strain on the ears from the spectacle sides. It also keeps the lenses in their proper position, supporting each between the side of the nose and the joint, so that rocking of the frame in both the vertical and horizontal planes does not occur. The base width can be measured, but is best given by a standard spread, which defines curve rather than actual width.

Standard Spreads are 1 cm. deep. They have two widths, the first being 2 mm. and the other 7 mm. from the apex of the curve, as follows:—

Standard No.	1.	2.	3.	4.	5.	6.
Upper chord in mm.	6	7·5	9	10·5	12	13·5
Lower chord in mm.	9	12	15	18	21	24

The spread, selected for distance and constant use, should fit the thin portion of the nose and not pass over the wider part; for presbyopia the spread should freely slide over the wider part; the latter is usually one spread wider than the former. A needed spread may, of course, be intermediate to two standard spreads.

The Depth of Bridge is the distance from the crest of the bridge to the backmost point. The usual depth is, say, 7 mm. but it varies, although not of necessity, with Ht. and Proj. To prevent rocking a **W** bridge needs to have a sufficient area of contact with the sides of the nose, and it should, therefore, project well behind the lenses so as to give the required support, but not so far as to interfere with the nasal duct. Regardless of Proj. it is advisable to have, if possible, at least a 7 mm. depth. The depth of a **C** bridge is the same as its Proj.

The Width of a Frame is the distance between the pins on which the sides are hinged; on the face the facial width is that between points a little beyond the outer canthi, opposite to the ends of the joints of the frame. The average width is about 110 mm., and is usually 45 mm. more than the P. D., but may be a little less or more. Joints should be long enough to prevent the spectacle sides indenting the sides of the head, but not too long for security or for cosmetic effect. If the face is relatively narrow the joints are needed short; if it is relatively broad compared with the P. D. the joints must be long.

The Length of a Curl Side is (*a*) the distance from the back of the joint to the plane tangent to the extremity of the curve and (*b*) the total length. (*a*) is usually about 110 mm. and (*b*) is about 50 mm. more than (*a*). On the face (*a*) corresponds to the distance from the tips of the lashes to the plane of the back of the ear.

A curl side should be straight to the top of the ear, and then take a sharp bend downwards, having a contour similar to, and just touching at every part of the back of the ear; the frame is thus kept in position without undue pressure at any point. Curl sides *always* require adjustment since they cannot, as manufactured, possibly fit the individual ears; also one ear may be farther back than the other. The tips should not project beyond, but should be hidden by, the lobes of the ears, and should be bent back at their extremities.

The tops of the ears are generally on a line with the eyes but sometimes are lower, or higher, and sometimes one is higher than the other. In these cases the sides should project straight backwards from the joints to about where the hair commences, and then be bent upwards or downwards, according as the eyes are high or low with respect to the eyes. If one ear be higher than the other each side must be adjusted accordingly, so that the lenses may be horizontally in line.

If the spectacle sides indent the sides of the face, they must be bent out near the joints, or opened more widely by filing the stops or knuckles of the joints, or, in extreme cases, the sides must be bent outwards at an angle, about an inch behind the joints. Pressure of the spectacle sides, on the front part of the head, causes the lenses to tilt upwards.

If lenses tend to slide forward, curl sides must be shortened ; if the lashes touch the lenses they need to be slightly lengthened ; this is easily achieved by manipulation. Curl sides should be *cable* or *spiral*, the latter being extremely comfortable and needing little if any adjustment.

The Length of a Straight Side is its complete length when flattened, and is, on the average, about 140 mm. ; on the face it corresponds to the distance from the tips of the lashes to a point about 30 mm. behind the plane of the back of the ear. Straight sides should have sufficient tension to hold firmly, and have a slight curve inwards corresponding to the shape of the back portion of the head, and they should be long enough to extend well behind the ears.

The Angle of Sides is the departure from 90° of the angle between the sides and the plane of the eye-wires ; the joints are angled along with the sides. Distance and constant-use frames have usually no angle, but presbyopic frames are, with advantage, angled 10° or even 15°.

The Size of Eye of a frame is obtained by comparison with standard sizes. The size of the required eye depends on the P. D. and usually the best, for ordinary dimensions, are as follows :—

P. D. under 60 mm. 2 eye. P. D. of about 60 mm. 1 eye.
P. D. of about 63 mm. 0 eye. P. D. over 63 mm. 00 eye.

The Eyes of a Frame when glazed must be of similar contour and truly elliptical ; if not the spectacle can never set correctly. The marginal outline itself should correspond, more or less, to the hollow formed by the brow and side of nose. In a glazed frame the joints must close in *their whole length*, with sufficient tension on the eye-wires to prevent any rotation of the lenses ; if the latter be loose they are easily chipped and sooner or later will fall out, if slightly too large, the joints cannot properly close, the frame is untrue and the lenses again are apt to become chipped or to crack.

The Bridge Wire.—The bridge is, or should be, attached to the eye-wires at their centres, from which the spurs project, straight backwards, or backwards and downwards. The inclination of the bridge is usually 30° to 45° with the horizontal, and the plane of the bearing surface of the bridge, at the crest, is at right angles to the bridge itself. Consequently as the bridge is higher, its bearing plane is more nearly horizontal, while it is nearly vertical or parallel to that of the face when the bridge is low. If the bearing surface of the bridge be not truly parallel to the nose itself, the skin may be chafed through and a bad sore created. Even when the slope is properly adjusted, the bearing surface must be large enough to prevent indenting the skin of the nose ; the heavier the lenses the more necessary it is to distribute the weight over a sufficiently large area. If the bridge is a good fit, the support at the sides lessens considerably the weight on the crest of the nose.

On account of the altered inclination of the crest, a saddle bridge can seldom be manipulated as to height; the latter can be increased and Proj. lessened, or *vice versa*, but when this is done the inclination of the bearing surface is usually such as prevents its being suitable for use.

Special Cases.—For clergymen and public speakers angled pantoscopic or clerical (half-eye) shaped eyes are useful, the bridge being of such a height that the upper part of the eye-wires lie just below the lower edges of the pupils.

A reversed pantoscopic, or half-eye form of frame, is sometimes useful for a myope who requires no power for close work which he sees beneath the lenses. Such a frame may serve for a myopic artist when sketching.

The height of the frame for bifocal lenses varies somewhat with their use. If worn constantly the dividing line, between the upper and lower lenses, should be just below the lower edge of the pupils when the eyes are directed to a point on the ground some 10 feet away ; *i.e.* in walking the ground should be visible through the upper lenses, with but a slight bending of the head. If their use is mainly when seated, the dividing line may be somewhat higher. Bifocals are not as a rule to be recommended for constant wear when moving about.

If lenses are required for such purposes as shooting, billiards, etc. the lenses should have a greater vertical diameter than the usual ; they may well be circular and should be centred somewhat higher than those for ordinary use. For billiards, or for target shooting, in which the eyes are rotated considerably upwards, the lenses may advantageously be angled upwards some 5°, or even more for shooting.

If the face or brows prevent the optical centres of the lenses being opposite to the centres of the eyes, or in the desired position, the eye-wires may be displaced, and the lenses decentred accordingly. For instance, suppose the brows are low and project, the eyes being deep set ; if the frame be placed beyond the brows the glasses are too far from the eyes and if placed beneath the brows they are decentred downwards. As a compromise they can be placed in the latter position and decentred upwards ; or the same effect may be, perhaps, obtained by using a round-oval form of lens, which is sometimes termed a half pantoscopic, *i.e.* partially flattened at the top.

To obtain the shape of the nose, if this be out of the ordinary, a piece of cardboard can be cut out so that the sides of the opening just touch the sides of the nose; or, better, a piece of leaden wire can be bent around the nose, and the shape, thus obtained, transferred to paper by tracing.

To Test a Spectacle Frame.—A spectacle frame should have—

1. The eye-wires in the same plane, so that a flat rule, laid across them, would touch simultaneously each of the eye-wires in two places, both above and below the bridge.

2. The joints in the same vertical plane, so that a straight horizontal line bisects both.

3. The sides opening to an equal extent, and parallel to each other; the sides when closed crossing midway between the eye-wires, with the tips, of straight sides, below the opposite joints.

4. The curves of the lower part of the bridge corresponding to each other: and both attachments of the eye-wires, if they are central, bisected by the same straight line passing through the joints.

If the frame does not set true on the face, the fault lies in one of the four above-mentioned factors. A spectacle frame cannot well be adjusted unless there are lenses in the eye-wires, so that the latter be of true form. A pair of metal templates, or a pair of strong Cx. lenses, should be inserted for this purpose.

Pince-nez.—The details of an eyeglass or pince-nez are:—

1. P. D.
2. Distance between placquets.
3. Size of eye.

Many of the particulars, given in connection with the fitting of spectacles, apply equally to eyeglasses. As a rule lenses for pince-nez are required rather larger than for spectacles, especially if they are rimless.

The *Canadian* has a flexible top spring and adjustable placquets; the *Jap* has a flexible top spring and fixed placquets. These are considered old-fashioned, but are still the best forms for presbyopes who desire a frame easily carried about, put on and off with the one hand, and at any desired angle. Although not the best form if there are fairly strong cylindricals, a quite accurate adjustment can be frequently obtained with them. They must, however, never be used as *folders*, since folding of the one eye over the other twists the top spring, and makes proper location impossible.

The *offset* has a flexible top spring and fixed placquets; it is good for constant wear and is the ordinary form for rimless pince-nez. There are, of course, many modifications of the regular type; the offset, when properly adjusted, retains its position by contact rather than by pressure.

A form of pince-nez generally termed the *finger-piece*, presents many advantages for some cases; it has a rigid bridge similar to that of a spectacle and placquets adjustable vertically and horizontally; the gripping tension is in the horizontal plane. The bridges have varying width, height and projection, and the P. D. required determines the size of eye.

The *astig.* has a rigid top bar, adjustable as to length, with fixed, rocking or adjustable placquets; it is the form most commonly employed in this country for constant wear, and for presbyopic purposes.

Eyeglasses are more complicated than spectacles, and need more consideration in their selection; their readjustment when out of shape is, however, easier. The source of the trouble must be in either the spring or the placquets and it can be easily located and corrected.

If the eyes are high in relation to the bridge of the nose the placquets must be low and *vice versa.* Inclining fixed offset placquets towards each other above in the vertical plane causes the lenses to be lower; less inclination raises them.

The more the placquets recede, the more generally secure is the hold of the frame. Flat noses and prominent eyes demand placquets that project well backwards, bold noses and sunken eyes are suited by placquets which recede but little, or lie in the same plane as the lenses. With fixed top bars the lenses are *true* horizontally if the placquets fit the nose on each side. Two great a spring tension of an eyeglass may cause headache and nervous symptoms, as well as redness, soreness and tenderness of the skin of the nose against which the placquets press. Cork placquets are perhaps more comfortable but hard rubber, or metal, are cleaner and on the whole preferable. If the centres of the pupils are unequally distant from the nose, the placquets of an eyeglass may need to be adjusted for each eye separately; some forms of offset pince-nez lend themselves readily to this adjustment; others do not and it may be necessary to have studs of different lengths, especially with astigs.; some pince-nez cannot be adjusted at all.

Eyeglasses, the same as spectacles, if worn constantly should be as near to the eyes as possible. Rigid placquets are to be preferred but they must be adjusted as to inclination and contour for each side of the nose; they should also have a slightly greater pressure at the top, to prevent tilting forward of the lenses. They must be in contact over their whole length in order that security of hold be obtained, because an eyeglass cannot fit, or be secure, if there are, for instance, convex placquets in contact with convex sides of a nose. Bending the top spring, at its attachment to the eye-pieces, alters the distance between, and the inclination of the placquets; flattening or rounding the top spring has similar effects.

Frame Selection.—As a rule eyeglasses are preferable to spectacles. They are more convenient to put on and take off, and they are more elegant. Many people who would refuse to wear spectacles, on account of their presumed disfiguring and aging effects, willingly wear rimless pince-nez, and the latter is the best form for constant use; there are very few noses that cannot be fitted with some form of pince-nez. The exceptions to this general rule of giving pince-nez are when the lenses are very strong, especially if cylindrical, and in the cases of children and quite old people.

White metal is really neater and more becoming for young people than gold or gold filled; gold frames should not be too heavy; steel frames need not be too finely tempered but should be light as to the wire and fine as to the joints.

Cosmetic Frames.—Spectacles may be needed for cosmetic effect, that is, to improve the appearance of the wearer. If one eye is blind and disfiguring, a dark smoke or blue lens will hide it, the other eye being fitted with a plano glass or a lens as may be needed. If one eye is small and useless for vision, or if an artificial eye be used which, of necessity, is smaller than the real one, a strong Cx. lens in front of it will increase its apparent size; conversely a strong Cc. lens will reduce the apparent size of an artificial eye which is, of necessity, large. If one eye be artificial, the use of tinted or even white lenses will, to a great extent, hide the fact. If one eye squints, and is useless for vision, a prism base towards the deviation improves the appearance, by causing the pupil to be seen more towards the apex.

Frame Measurements with the "Orthops" Rule.

SPECTACLES.

Height of Bridge.—The frame is placed so that the lower edge of the rule bisects the joints. The height "up" is read on the vertical scale above the edge. Height "down" is read below the edge. The reading is made at the middle of the bridge wire, it being the No. covered by the wire.

Proj. of Bridge.—The frame is placed with the backs of the "eyes" against the lower edge of the rule and the bridge astride the projection. "Set-out" is read on the vertical scale below the edge. "Set-back" is read above the edge. The reading is made at the middle of the bridge wire.

Base of Bridge.—The bridge is placed with the inside of the bridge at the left edge of the projection and the distance is read on the upper scale. The reading is made at the widest points of contact with the nose.

P. D.—The frame is placed with the inner side of one eye at the left edge of the projection and the distance is read on the upper scale to the outer extremity of the other eye.

Front.—The frame is placed with one pin at the left edge of the projection and the distance is read on the upper scale to the other pin.

Total Length of Side.—The frame is placed with one joint at the left edge of the projection and the distance is read on the upper scale to its extremity when flattened.

Length to Tangent of Curl.—The frame is placed with the joint near the end of the projection at the left and the distance is read on the upper scale.

Angle of Sides.—The frame is placed with the *left* eye-wire against the right end of the rule with the joint at the centre of the protractor, on which the angle, between the eyes and sides, is then read.

Curve of Straight Side.—The frame is placed with the joint to the left of the projection, and the extremity of the side to the right, both at the lower edge of the rule; the greatest depth of curve, or the sagitta, is then read on the vertical scale.

EYEGLASSES.

P. D.—The frame being opened as when in use, this distance is taken as on a spectacle frame.

Distance between Placquets.—The frame is placed with the inside of one placquet at the left edge of the projection and the distance is read on the upper scale to the inside of the other placquet.

For oscillating placquets the distance between them is taken at the centre.

For fixed straight placquets the distance is taken at the top and bottom.

For fixed curved placquets the distance is taken at the top, centre and bottom.

These measures are taken when the frame is at rest, or when extended if the P. D. be known. The lengths of the placquets should also be taken when necessary.

Unequal Placquets.—When the two placquets differ, the distances of each from the median line should be taken separately. The rule is turned so that the frame can be placed across the vertical scale with the middle of the spring or bar bisected by its zero line; the distance is then read on each side from this central line.

Bridges or Springs.—The length is taken on the upper scale between the inside extreme points measured horizontally.

Use of the "Orthops" Rule with Lenses.

To Locate the Axis of a Cylindrical.—Holding the lens and the neutralizing cylindrical firmly together and geometrically centred, they are placed against the end of the rule so that its edge exactly coincides with the long diameter of the lens, and its middle point with the centre of the lens. The position of the axis is then indicated on the protractor by the small scratch on the neutralizing cylindrical. The lens should not be laid flat, but held at a small angle with the rule, and the outer face of the lens must be upwards.

To Locate the Optical Centre.—The lens is held in a plane parallel to that of the rule, and a few inches above it, over the intersection of the vertical and horizontal scales. The optical centre is opposite to the intersection of the horizontal and vertical edges when these edges are seen continuous within and beyond the periphery of the lens.

To Measure Decentration.—The geometrical centre is marked with a dot of ink, and the optical centre being located as above, the distance on the horizontal scale, between the optical and geometrical centres, is read —this gives the horizontal decentration ; or the decentration vertically is read on the vertical scale.

To Measure a Prism.—The rule is placed 1 m. distant from the prism which is to be measured, the base of which is to the left opposite to the projection. The base apex line must be exactly parallel to the horizontal edge of the rule. This edge being viewed through the prism, the projection is seen deflected to the right, and its right edge indicates on the lower scale, seen above the prism, the amount of displacement in cm. and fractions thereof. The number of cm. indicated equals the number of prism diopters. Care must be taken that the displacement is minimum

To Calculate Resultant Prisms.—The oblique distance from a point on the horizontal edge as many cm. from 0 as there are units of horizontal prismatic power, to a point on the vertical edge as many cm. from 0 as there are units of vertical prismatic power, is measured. This distance in cm. and fractions thereof equals the number of units of strength and fractions thereof in the resultant prism; the angle which the oblique line forms with the horizontal is the angle which the base apex line of the resultant prisms also forms with the horizontal.

Weights of Spectacles and Eyeglasses.—The thickness of a spectacle lens varies with its power and, if strong, also to some extent with its size. An ordinary concave is about 1 mm. thick in the centre and about 2 or 3 mm. at the periphery. Convex lenses average from 2 to 3 mm. thick at the centre.

The weight of a pair of lenses varies with the size and the thickness; an average weight may be 3 to 5 dwt. An average frame weighs 2 to 3 dwt., so that the total weight of frame and lenses is about, say, 6 dwt.

American Standards with their long and short axes:

4 Eye	33·8 × 24·5 m/m	1 Eye	36·5 × 27·5 m/m	000 Eye	40·9 × 31·9 m/m
3 Eye	34 × 26 m/m	0 Eye	37·8 × 28·8 m/m	0000 Eye	44·3 × 36 m/m
2 Eye	35 × 25·5 m/m	00 Eye	39·7 × 30·7 m/m	Jumbo Eye	46 × 38 m/m

Optical Society Standards :

			Long Diameters.					
O.S. No.	Length of Periphery.	Corresponding American No.	Oval	Long Oval.	Round Oval.	Pantos.	Half Oval.	Round.
1	92·5 mm.	4	33·5	35	31	34	36	29·5
2	94·5 ,, = 92·5+2	3	34	35·5	31·5	34·5	36·5	30
3	97·5 ,, = 94·5+3	2	35	36·5	32·5	35·5	37·5	31
4	101·5 ,, = 97·5+4	1	36·5	38	34	37	—	32·5
5	106·5 ,, =101·5+5	0	38	39·5	35·5	38·5	—	34
6	112·5 ,, =106·5+6	00	40	41·5	37·5	40·5	—	36

The ratio of the long to the short axis of the *oval* is approximately 1·3 to 1, that of the *long oval* 1·5 to 1.

Ophthalmic Lenses may, of course, be made up in a variety of forms but the two most generally in practical use are the double and the periscopic. With regard to the former little need be said here beyond the fact that the term is not confined to those lenses having the same curvatures on both sides, but also includes all cases where the surfaces, although not necessarily equal, are of the same nature, *i.e.* both Cx. or both Cc. The second form is the periscopic, which is Cx. on one side and Cc. on the other, no matter what the actual curvatures may be; the intermediate form of plano Cx. or Cc. is not now employed. We may use the terms *double* and *peris.* to include sph.-cyls. with both surfaces of the same or opposite nature, respectively, as well as for simple sphericals.

The Meniscus or Periscopic is the best all-round form for ordinary powers since, with it, oblique vision is better and there is a larger field of clear vision on rotation of the eyes; side reflections of light are prevented and the frame generally can be placed nearer the eyes. The ordinary trade Cx. periscopic has a Cc. surface of from 1·25 D. to 2 D., and the periscopic Cc. has a Cx. surface of similar powers, but with these improvement in oblique vision is small, and any changed effectivity due to the refracting plane being outside the lens is negligible, this latter being governed not only by the thickness of the lens, but also by the relative curvature of the surfaces.

The deep meniscus spherical is one where the periscopic effect is enhanced by making the – curve on Cx. lenses, or the + curve on Cc. lenses deeper than usual; thus a 1 D. may have powers of – 6 and + 7, or a – 1 D. powers of + 6 and – 7. Deep menisci, although eliminating most of the oblique aberrations and enlarging the field of view, cannot sometimes be worn with comfort by people accustomed to the ordinary form of lens. One of the disadvantages is that there is marked distortion in oblique vision, which is all the more noticed owing to the absence of other aberrations; another is that difference in size of the retinal images may become appreciable when the lenses are of unequal power, it being impossible to place the optical centres in the anterior focal planes. Further, with medium to strong powers, the V. A. with a deep meniscus or toric may, on account of the change in effectivity, differ appreciably from that obtained with trial lenses. All these, however, are quite minor defects.

The Toric or Toroidal is a special form of astigmatic lens having two different principal powers on the same surface, which has a curvature resembling that of a spoon or egg. The toric surface is equivalent in effect to two crossed cylindricals and the other surface may be spherical or plano, so that the total effect is that of a sph.-cyl. The toric is to be recommended where a high sph. power is required with a weak cyl., *e.g.* where the combination calls for +11 S. ⊂⊃ + 1·0 C. Ax. 90°. Instead of all the sph. power being on the one surface and the cyl. on the other, the effect may be obtained from +5 D. sph. on the one surface while the other is a toric of +6 D. in the vertical and +7 D. in the horizontal meridian; that is, sph. + 5 D. ⊂⊃ toric +6 D. and +7 D. A combination of −16 S. ⊂⊃ −2·0 C. Ax. 180° can be obtained from a combination such as sph. −10 D. ⊂⊃ toric −6 D. and −8 D.

The toric is also a desirable form of lens where a greater periscopic effect is needed than can be obtained from an ordinary sph.-cyl. Thus suppose the combination is +2·0 S. ⊂⊃ + ·5 C., the best form of which would be +2·5 S. −·5 C. As a toric with a base curve of +6 D. it would be sph. −4 D. ⊂⊃ toric +6 D. and +6·5 D. There would be no advantage in a periscopic toric, if the combination needed were such as would have a sufficiently high Cc. surface in the ordinary form as, for instance, −5·0 S. ⊂⊃ −2·0 C. which can be made up as −7·0 S. ⊂⊃ +2·0 C.; or with, say, −4·0 C. which may take the form of −4·0 S. ⊂⊃ + 4·0 C.

The Bifocal, as its name indicates, is a lens of two different powers or foci set into the same eye-wire. Of the two powers the upper is used for distance and the lower for reading or close work. In the Cx. bifocal the upper is the weaker and in the Cc. the reverse is the case. A bifocal can also be made to have Cc. power for distance and Cx. for reading. There are various forms of bifocals, many having fancy names, but the following are the chief styles:—

1. The *Franklin*, or *split*, is made of two lenses cut and joined, the juncture being a straight line which can be at the centre or above or below it.

2. The *perfection*, which is a modification of the split, the juncture being curved.

3. The *solid*, old style or up curve in which the stronger lower part is ground on to the weaker upper.

4. The *solid*, new style or down curve in which the stronger lower part is ground on to a small portion only of the weaker upper.

5. The *cement* consists of a thin segment of the required additional power cemented on to an ordinary lens of the strength required for distance. The segment can be made so thin as to be almost invisible.

6. The *Borsch.* This has been made by inserting a strongly curved small lens of high μ between two Cx. plano lenses of low μ.

7. The *fused* is made by fusing a strongly curved small lens of high μ on to the weaker main lens of low μ.

8. The *inset.* In this a space is ground out from the main lens and a small lens of higher μ set in it.

No. 3 is a bad form since it is decentred; but all the others have some advantages. The *cement* is the most generally employed and, if the wafer is thin, is an excellent form for its cost; it is, however, often decentred on the lower part owing to want of proper attention in the cutting of the segment; also sometimes the cement decomposes, and renders the lower part opaque. In some forms of fused bifocals, a certain amount of decentration, and chromatism of the reading power, is unavoidable.

The *Lenticular* or *New System*, where the central power is greater than that of the periphery, is a special form of bifocal which does away, to a great extent, with the prismatic effects occurring in oblique vision through strong lenses. Thus a +2 D. plano Cx. may have, on its plane surface, a central segment of, say, +4 D. sph.; or a −3 D. plano Cc. may have a *central* portion of the other surface concaved to any extent.

The STENOPÆIC LENS is one of small aperture, the latter taking the form of a large pinhole, a slit or other shape. Temporary stenopæics can be made by fastening black paper, or sticking plaster, to ordinary lenses; the apertures can thus be readily changed as found requisite.

The MONOCLE, or OXFORD, is a circular single lens milled around the edge or mounted in a ring. Its constant use is indicated only when one eye is defective, and the other is not used for vision, or when the one is more defective than the other eye, so that the Oxford equalizes them. It is also a permissible and very useful article for a myope of low degree to improve distant vision for a short time, or for a presbyope to inspect objects or see figures, etc., which would not, otherwise, be clearly visible. It is better mounted with a *gallery* which aids in keeping it in place.

The MAGNIFYING GLASS or READER is used in defective sight (incipient cataract, etc.) in order to make print legible; the rectangular form held parallel to the print is the best. A reader, employed with a pair of spectacles, may sufficiently increase the size of ordinary type to make it legible in cases where reading would otherwise be impossible.

The ORTHOSCOPIC LENS has a certain prismatic effect proportional to its spherical power, but is little used, its principle being faulty; various other names have been given to this style of lens.

The Hyperbolic Lens is one having a concave hyperbolic curvature for the correction of conical cornea (*q.v.*).

The Contact Glass is a thin shell, to be worn in contact with the cornea, in irregular astigmatism, etc. Its use has not proved satisfactory, and it tends to set up inflammation in the outer coats of the eye.

Forms of Protectors.

The D Eye has coloured plano glasses cut in the shape of a D, and hinged lateral flaps which prevent the light from entering the eyes at the sides, when it is worn; it is largely used in India and other tropical countries.

The Globular or Coquille has large, coloured glasses of globular shape used to mitigate the intensity of the light. The cheaper grades have glasses which are blown and of a poor quality, being full of flaws and acting as imperfect concave sph.-cyls.; the better qualities have properly worked glasses forming deep menisci without power. Coloured plano glasses serve the same purpose and are often, if not generally, preferable.

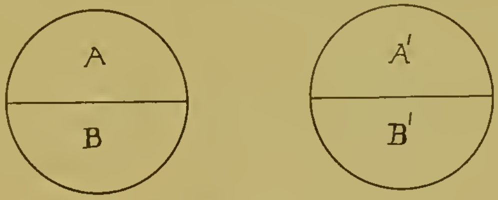


Fig. 148.

The Goggle or Protector has plano white or coloured glasses in a wire gauze mounting, or they are made entirely of wire. Other forms have mica, celluloid, etc., which may be white or coloured, and in various shapes and sizes, according to the use to which they are put. Protectors should always be used in occupations where injury from intense light, or from flying particles, may occur to unprotected eyes, as with furnace men, threshers, stonemasons, etc.

The Hollowed Eye Shell is made of rubber or celluloid, and allows the eye to be opened, in case of disease, while the light is entirely excluded; the effect is the same as that of a dark room.

Missing Lens of a Bifocal.

If from a bifocal one part of one of the lens is missing, it can be calculated as follows: Suppose B′ in Fig. 148 were missing. Its cyl. element is the same as that of A′; its sph. is the same as that of A′ plus the same difference as there is between A and B. If the cemented segment only is absent, its power is that of the segment of B.

For example suppose—
A is + 3·0 S. ⬭ + 2·0 C. Ax. 40°, and B is + 4·5 S. ⬭ + 2·0 C. Ax. 40°.
A′ is + 1·0 S. ⬭ − 3·0 C. Ax. 120°;
then, by calculation, B′ is + 2·5 S. ⬭ − 3·0 C. Ax. 120°.

Again, suppose A and B are as above, while A′ is missing. If B′ is − ·5 S. ⬭ − 1·5 C. Ax. 20° then A is − 2·0 S. ⬭ − 1·5 C. Ax. 20°.

Points on Frames and Lenses.

For frame adjustment, two pairs of small pliers having smooth jaws should be used.

To learn how to readjust, or set spectacles, it is advisable to practice with old frames purposely put *out of true.*

The length and form of cable curl sides are altered by working them between the finger and thumb, until they have the desired form.

If the one side of a frame is lower than the other, the opposite eye is lowered when in use. If one eye is inclined out the opposite eye is advanced.

Generally the bending of metal parts, and of hard rubber, metal and celluloid placquets is best done with pliers, but the fingers can often be very advantageously used for this work; cork or soft rubber placquets should be bent by the fingers, as pliers damage them.

To Detect Imperfections in a Lens hold it against a dark background and let light be reflected from it obliquely; flaws or scratches can then be readily seen by moving the lens about.

For marking lenses a grease pencil should be used.

Lenses made to a prescription should be revised by neutralization, or by a lens measure, before delivery to a customer as, however much care be taken by the manufacturing optician, occasional errors cannot be avoided.

Interchangeable cylindricals, ordered without frames, should have grease pencil marks to show the axes so that they may be placed correctly in the frame.

The spectacle front must face the optician, when considering the direction of the axis of a cylindrical.

Before removal of lenses from a frame they should be marked *right* and *left*, also the *top* and *outer surface* of each should be indicated; they can then be replaced without trouble in proper position.

To clean soft rubber or cork placquets, use warm water, soap and brush and dry thoroughly. A spirit, such as petrol, is also useful.

If a screw be too tight to turn, press hard upon it or, if necessary, tap the point with a small hammer, or heat slightly.

To prevent off-set placquets becoming loose, as they frequently do, compress with pliers the sides of the box against the screw-plate of the placquet spur.

Sometimes gold frames turn black, and this may occur if 18 ct. It is due to chemical action of the perspiration, or to hair dye, complexion lotions or medicines, especially those containing sulphur or mercury, or even to chemicals used on furs, or clothing, or to proximity to vulcanized articles.

Bridges and Sides.—In addition to the *saddle* or W and *crank* or C bridges, there are the *arch* or U, the *snake*, the X and the K bridges.

The arch serves the same purpose as the crank, and is needed when the nose is very wide compared with the P. D.; it forms a single arch from the one eye-wire to the other.

The snake is useful for low flat noses as found among Chinese and Negroes; it is level and flush, or the projection may be negative.

The X or K bridge, combined with straight sides, is sometimes useful for reversing the lenses when the one eye is useless. The same result can be obtained with an upright C or U bridge, the sides being curl, or turn-pin, and reversible.

In addition to the *straight* side and *cable curl* side, there are the *solid curl*, *half curl*, *turn-pin*, and *slide* sides. The solid curl is of thin flexible wire not twisted or coiled. The half curl is a stiff side bent downwards to engage the ear; it is very useful for certain cases where the ordinary straight sides are hardly secure enough, as in factories. The turn-pin is hinged at the middle, so that the back part can be turned down behind the ear. The slide is made so that the back portion can lie over the front portion, and the whole frame occupies a lessened space, when not in use. These last two are now however, antiquated.

The Typoscope is recommended by its inventor, Mr. Charles Prentice of New York, as an aid to reading, in conjunction with spectacles, where there is defective sight, as in amblyopia, cataract and high Am. It is a plate of black hard rubber or cardboard 7 × $2\frac{1}{4}$ ins., having a rectangular aperture $4\frac{1}{4} \times \frac{3}{8}$ ins. This opening is placed over reading matter and moved line by line; the plate is larger on one side so that its projection beyond the page facilitates its being moved.

Artificial Eyes.

An artificial eye should be first used only by direction of the surgeon, the usual period after enucleation being five or six weeks; it not only improves the appearance, but also tends to keep the orbit and lids healthy. It may be of ordinary single shell style, which is suitable where there is a good stump, or of the double shell (Snellen) style, which is preferable where there is little or no stump.

The *size* is important; if too small the eye looks sunken and does not support the lids properly; if too large it causes discomfort and irritation of the parts, and limits mobility.

The suitable shape is best found by selection, and must be that which causes the iris and pupil to be in correct position, as well as producing comfort, mobility and the maximum conformity with the other eye.

The *iris* should correspond in colour to that of the good eye, and the size of the *pupil* also when the eyes are facing a good light since, in that position, any difference would be most noticed.

The *surface* must be smooth so as not to cause irritation ; use roughens it owing to the action of the secretions of the orbit and lids ; the eye should then be replaced or repolished;

To *select* an eye, one from stock may serve for size or shape, another for colour and yet another for pupil ; the required eye must be ordered accordingly. It is almost impossible to order one from description and dimensions.

To *introduce* or *remove* the eye the wearer should stand before a mirror, and have a cushion or napkin in front in case the eye should drop.

To Insert.—Dip the eye in water, slightly raise the upper lid and slip the eye underneath, the wide portion to the temporal side. Holding it in position and looking downwards, depress the lower lid and slide over the eye, which will then drop into position.

To Remove.—Pull down the lower lid, insert a small, clean, blunt probe behind the eye, and guide it out from the socket.

At night the eye should be removed and kept in water, and the surgeon will doubtless instruct that the orbit itself be cleaned and dried, to keep it in a healthy condition.

INDEX

Those numbers in heavy type indicate chapters or main articles on particular subjects. The subheadings to the articles serve as further guides.

THE END

BILLING AND SONS, LIMITED, PRINTERS, GUILDFORD

ORTHOPS SPECIALITIES.

THE ORTHOPS CHART.

A complete self-contained chart designed for the most modern system of sight testing. Every detail has been determined or calculated with a definite object, and on scientific principles.

THE ORTHOPS NEAR MUSCLE-TEST.

It is now generally recognized that a complete knowledge of the muscular imbalance cannot be obtained from the distance-test alone. The Orthops near muscle-test, which has been designed to afford such a near test at the customer's ordinary reading point, is small and inexpensive, and no refractionist should be without it. It is employed in the ordinary way with the Maddox rod or groove, enabling the imbalance for distance and near to be compared almost simultaneously.

THE ORTHOPS TRIAL-FRAME.

This frame combines all the simplicity and rapidity in use of the best variety of drop frame combined with all the necessary facial adjustments. In it the clumsy and painful hook sides have been abolished in favour of long powerful straight sides which keep the frame firmly yet comfortably in place. It is hand-made, and therefore light and rigid ; it holds three lenses in each eye, and the broad swinging bridge adapts itself to any type of nose.

THE ORTHOPS FRAME AND FACE-RULE.

This well-known rule is practically unique in that with it facial and frame measurements can be taken with equal ease and accuracy. Made in boxwood or xylonite. Full descriptive pamphlet on application.

Orthops Specialities can be obtained from all Wholesale Optical Houses.

ORTHOPS SPECIALITIES.

THE ORTHOSCOPE.

An instrument forming a fixed Ophthalmoscope, capable of giving, with the ordinary size of pupil, a perfect picture of the fundus. The field of view is three inches in width, and the magnification ten diameters. For a small extra charge the Orthoscope can be adapted for efficient retinoscopy.

◆

THE ORTHOPS POINTER.

A handy instrument enabling far and near points to be measured with quickness and accuracy. An essential in the testing-room.

◆

THE ORTHOPS RETINOSCOPE.

Specially designed to increase the illumination in cases of high ametropia, etc., where the reflex is very dull and sluggish, and therefore practically invisible with the ordinary plane or concave mirror.

◆

THE ORTHOPS RECORD-BOOK.

Complete in every detail for the practical refractionist, and without the mass of confusing spaces for unnecessary data so frequently found in record-books.

◆

THE ORTHOPS TANGENT-SCALE.

A conveniently arranged scale for giving measurements in either prism-diopters, degrees, or degrees of deviation.

◆

THE ORTHOPS OPHTHALMIC BRACKET.

An ideal bracket, giving all the necessary positions, but having the minimum number of joints. Rigid and well made, complete with reflector, cover, and iris diaphragm.

Orthops Specialities can be obtained from all Wholesale Optical Houses.

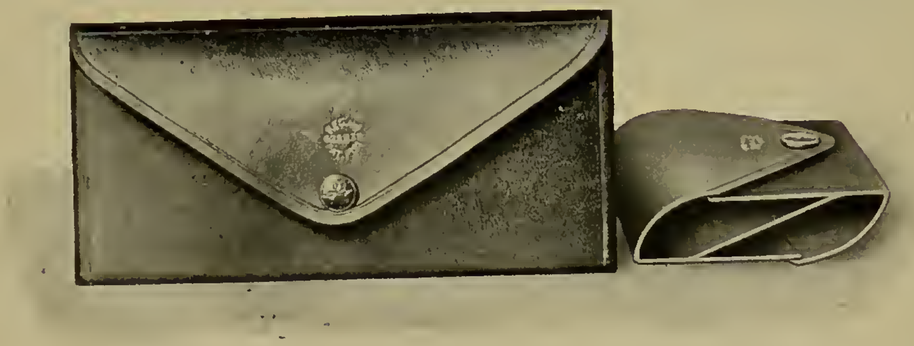
"DUPLEX" CASES.

(Patent No. 3240/13.)

Designed to accommodate two pairs of eye-glasses, or two pairs of spectacles, or one of each.

The accompanying illustration indicates how a diagonal partition separates the overlapping two pairs of glasses, with the most important result that

THE "DUPLEX" CASE IS CAPABLE OF CONTAINING TWO PAIRS OF GLASSES WHILE BEING SCARCELY MORE BULKY THAN A SINGLE CASE.



As every optician knows, customers complain of the inconvenience of carrying two cases when, as very frequently happens, they require to have about them two pairs of glasses.

THE "DUPLEX" CASE REMOVES THIS CAUSE OF COMPLAINT.

In many an instance two pairs of glasses would be purchased if they could be carried conveniently.

THE "DUPLEX" CASE ALLOWS THIS TO BE DONE.

Surely no optician will neglect the opportunity of selling two pairs of glasses instead of one.

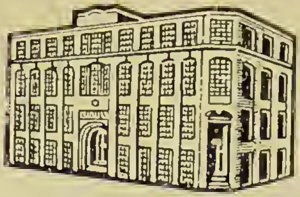
THE "DUPLEX" CASE VERY STRONGLY OFFERS THIS OPPORTUNITY.

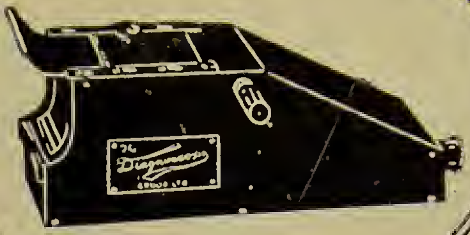
"Duplex" cases are made in various qualities and in two sizes—for two pairs of eye-glasses or for two pairs of spectacles.

They can be obtained from all wholesale optical houses, or direct from the manufacturers :

WILLMOTTS, LTD., EVESHAM, Worcs.

And 55, HATTON GARDEN, LONDON, E.C.





The

"DIAGNOSCOPE"

The last word in Instantaneous Ophthalmoscopy.

THIS instrument is unique in that no lenses at all are employed to produce the image of the fundus oculi, yet at the same time a highly magnified picture and extensive field of view is obtained with the utmost clearness.

SEVEN POINTS ON THE DIAGNOSCOPE:

1. Its action is simple, no previous knowledge of optics or ophthalmoscopy being required by the user.
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4. By means of the focussing eyepiece, all strain on accommodation is relieved, and the fundus viewed under the most comfortable conditions.
5. All unpleasant proximity of subject and observer is obviated.
6. Provided the instrument is not dropped or violently jarred, there is nothing whatever to get out of order.
7. It is extremely portable, being only 7¾ in. × 3 in. × 1¾ in. in size.

It is a perfected instrument, which no optician should be without. It is sold in a neat, compact, leather-covered case, fitted with lock and key, complete with spare lamp and pocket battery, for

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THE "DEFIANCE"

(In 1/10 12-Kt. Gold-filled, and 10-Kt. Solid Gold),

FINGER-PIECE MOUNTING

Is the neatest mounting; the last word in this type of Spectacle Ware.

Made with Platinum-lined Guards, Shell Guards, Cork Guards,
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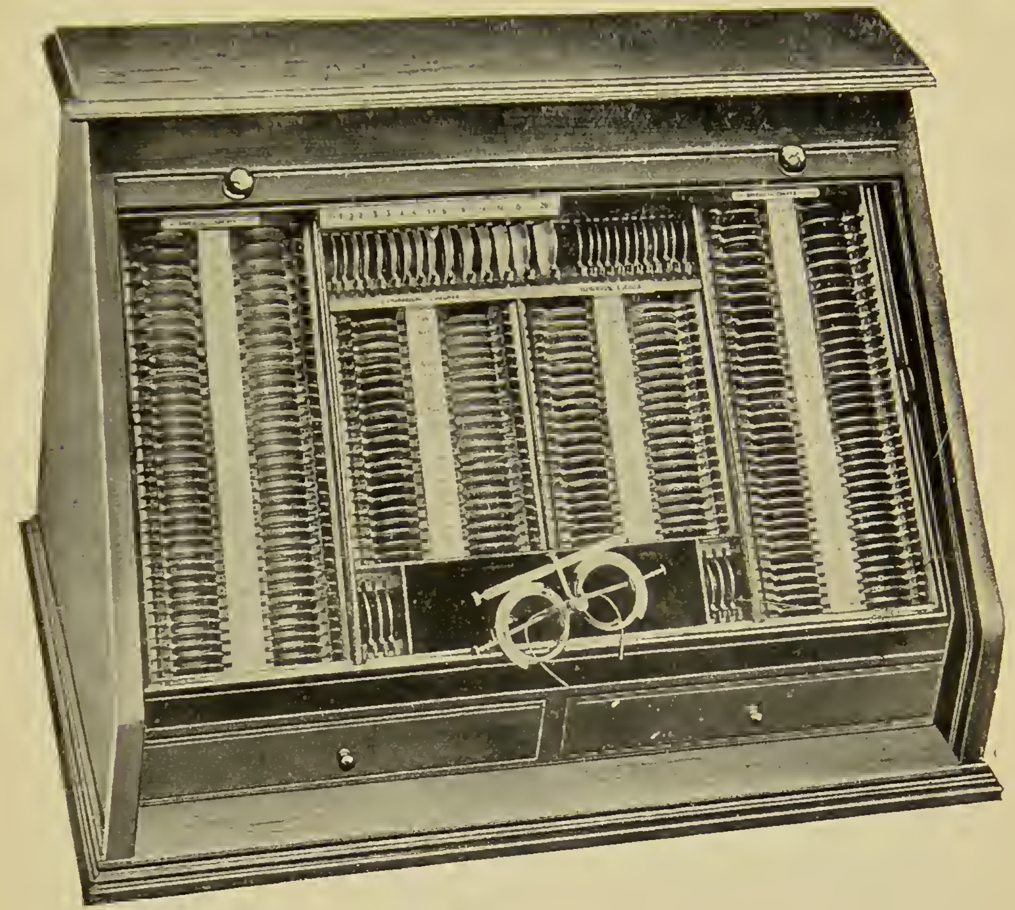
¶ *N.B.—To save needless correspondence we beg to notify the Trade that the "Defiance" Mounting can be supplied through the recognized wholesale houses only.*

The "HARLEY" Roll Top Trial Case.



Advantages :

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(*c*) CONTENTS BETTER DISPLAYED.

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Contents.—30 Pairs Convex and Concave Sph. Lenses, 0·25 to 20 D; 18 Pairs Convex and Concave Cyls. 0·25 to 6 D; 12 Prisms 1° to 12°; 6 Smoke Lenses; 6 Blue Lenses; 2 Stenoptic Discs; 1 Pinhole Disc; 1 Blank Disc; 1 Single Trial Frame; 1 Double Trial Frame. Price **£4 15s.**

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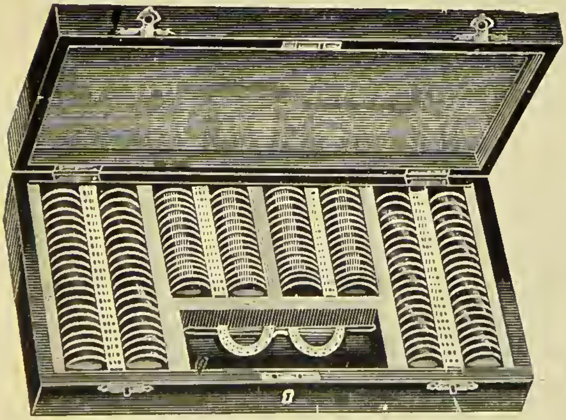

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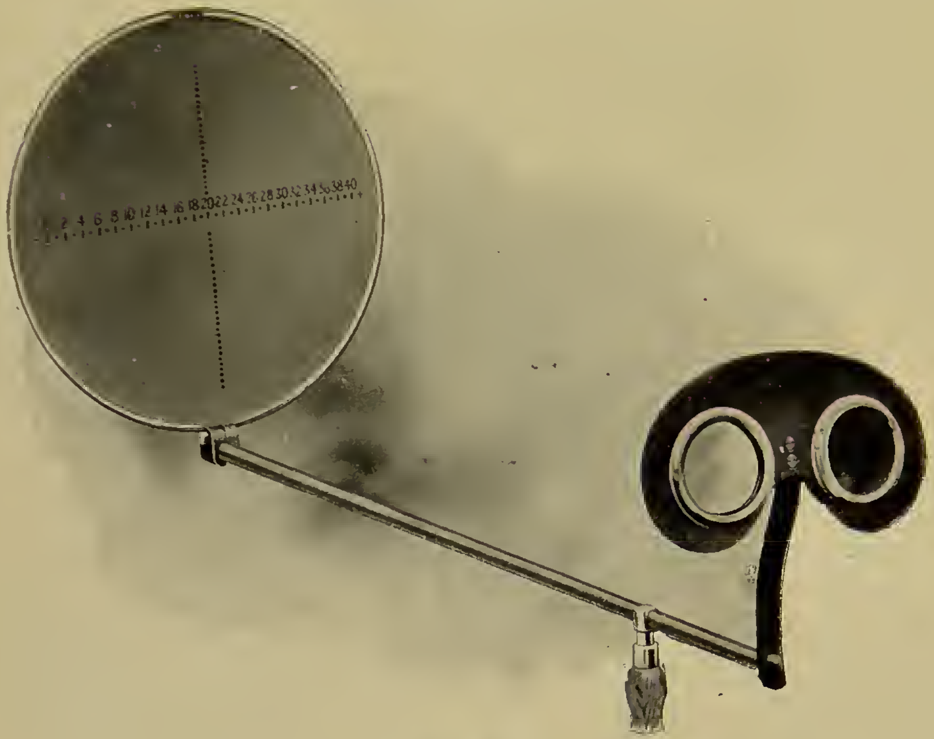

No. 10917.

This recent invention of Dr. Maddox has been exceptionally well received, and there is no doubt that it will speedily rank as the standard test for muscular imbalances.

It will be seen by the illustration that it takes the form of a hand instrument, to be held by the patient.

It has two eyepieces of neutralizing colours, attached to a rod 33 cm. long. At the other extremity is a disc, opaque except for two designs which are made translucent and of neutralizing colours. The horizontal consists of a green scale with figures above. This is intersected at right angles by a red dotted vertical line. The amount of any existing esophoria or exophoria can be immediately measured, being indicated by the dioptric divisions on the scale.

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EACH INSTRUMENT IS PACKED IN A NEAT BOX.

No. 10917, £2 2 0 **No. 10917*f* (Folding Pattern), £2 5 0**

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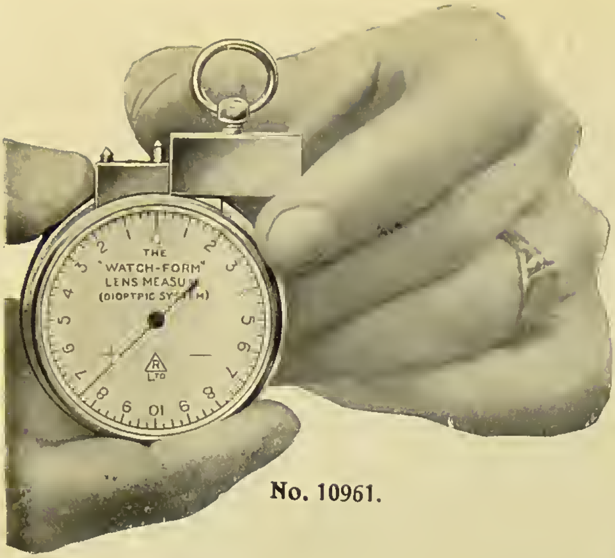

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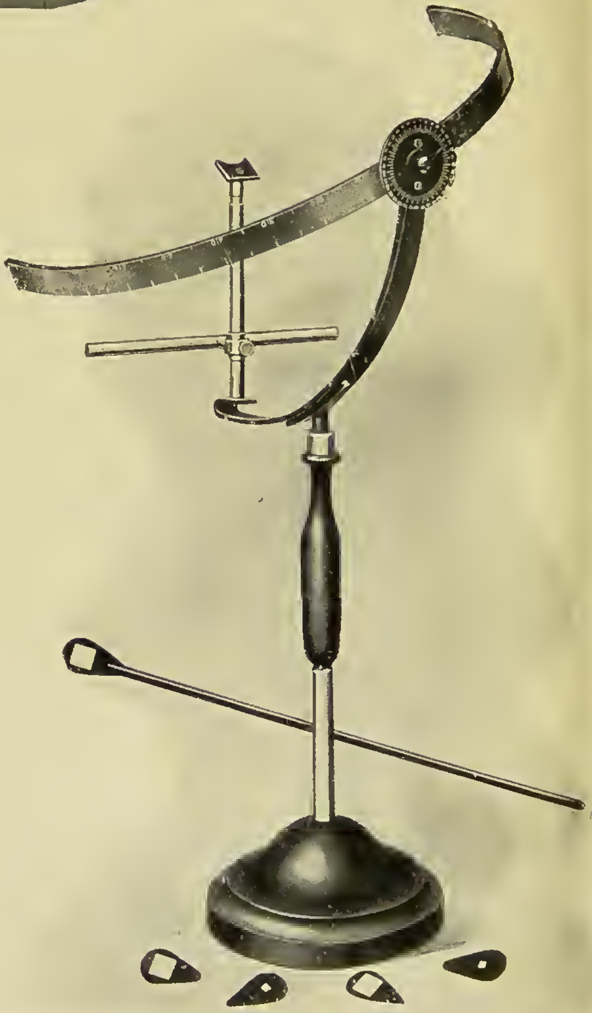

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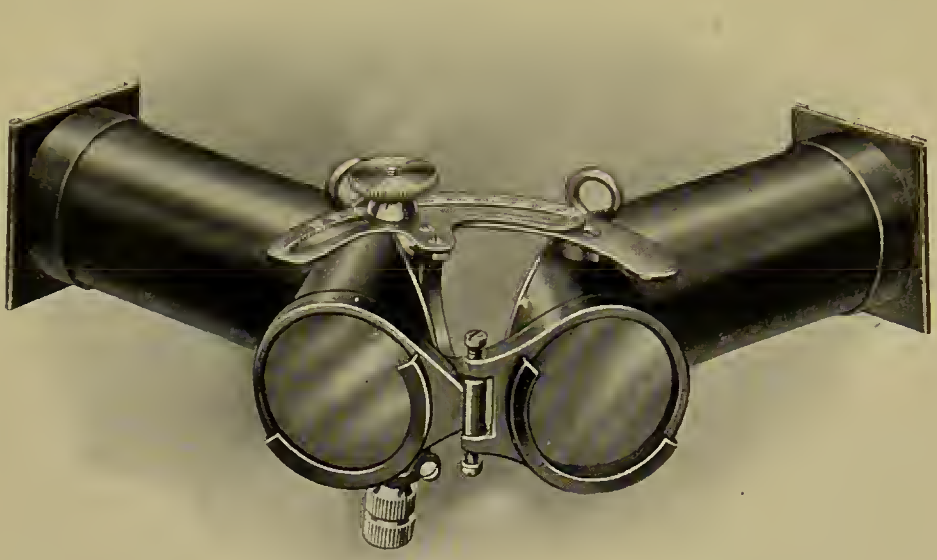
THE
WORTH-BLACK AMBLYOSCOPE.



No. 10833.

This is an improved instrument for fusion training; it trains an amblyopic eye to see.

It was originally devised by Dr. Worth with horizontal adjustment only. The vertical adjustment was afterwards devised and added by Dr. Black of Milwaukee.

PRICE COMPLETE, WITH SET OF 12 PICTURES,

No. 10833, **£1 18s. each.**

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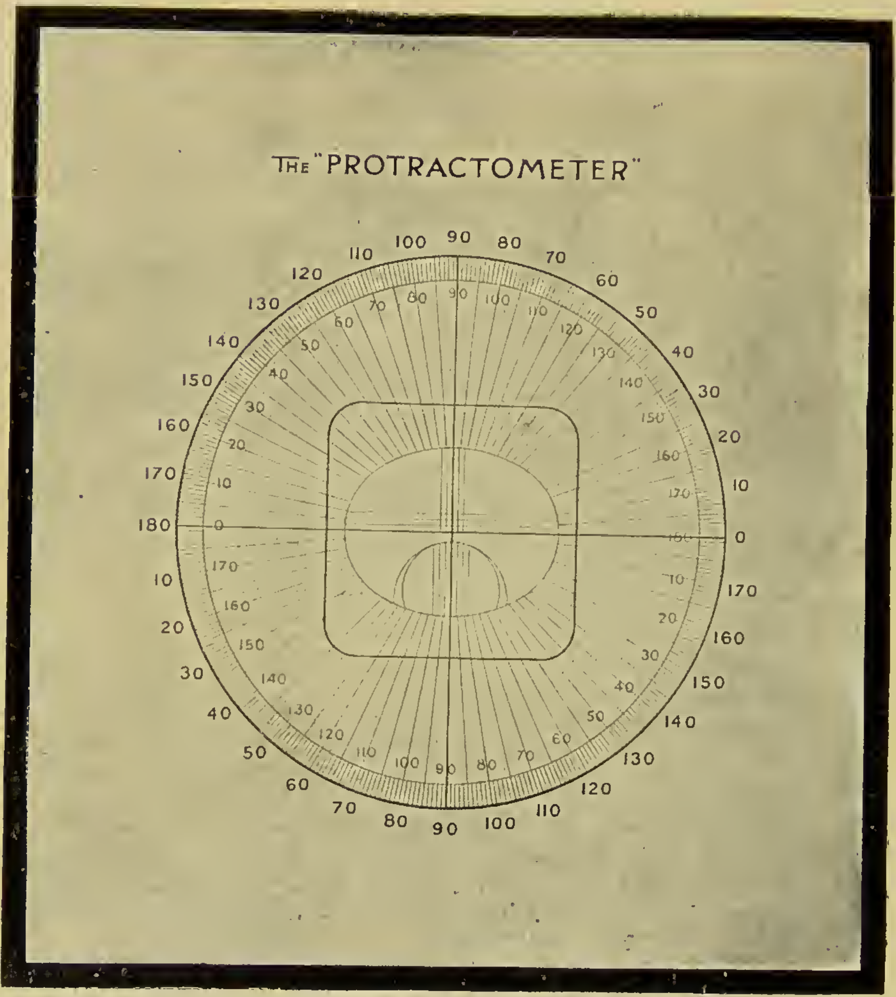

A new form of Optical Protractor for the checking and setting of spectac lenses. Exceptionally useful for Bi-focal lenses.

It has an ivorine surface, and is mounted on metal, size $6\frac{5}{8}$ in. × 6 in.

No. 11561, **Price 2s. each.**

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The "INTERNATIONAL" CURLSIDE RULE.

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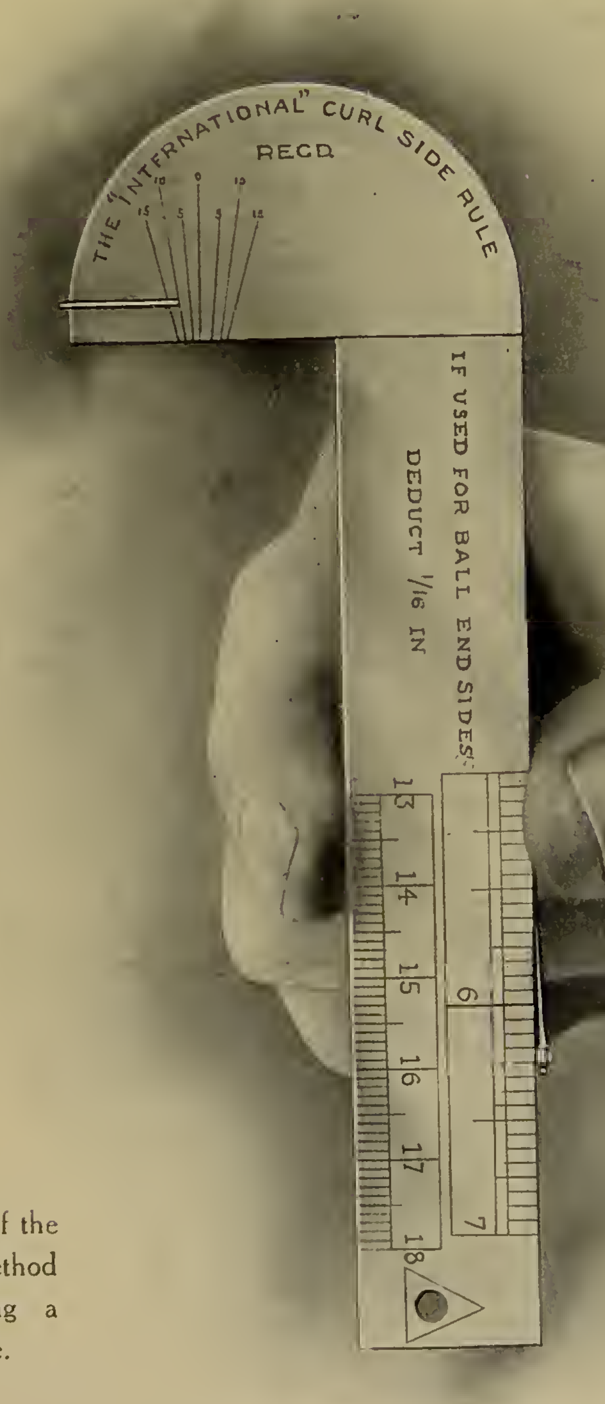

Illustration of the Rule and method of measuring a Curlside.

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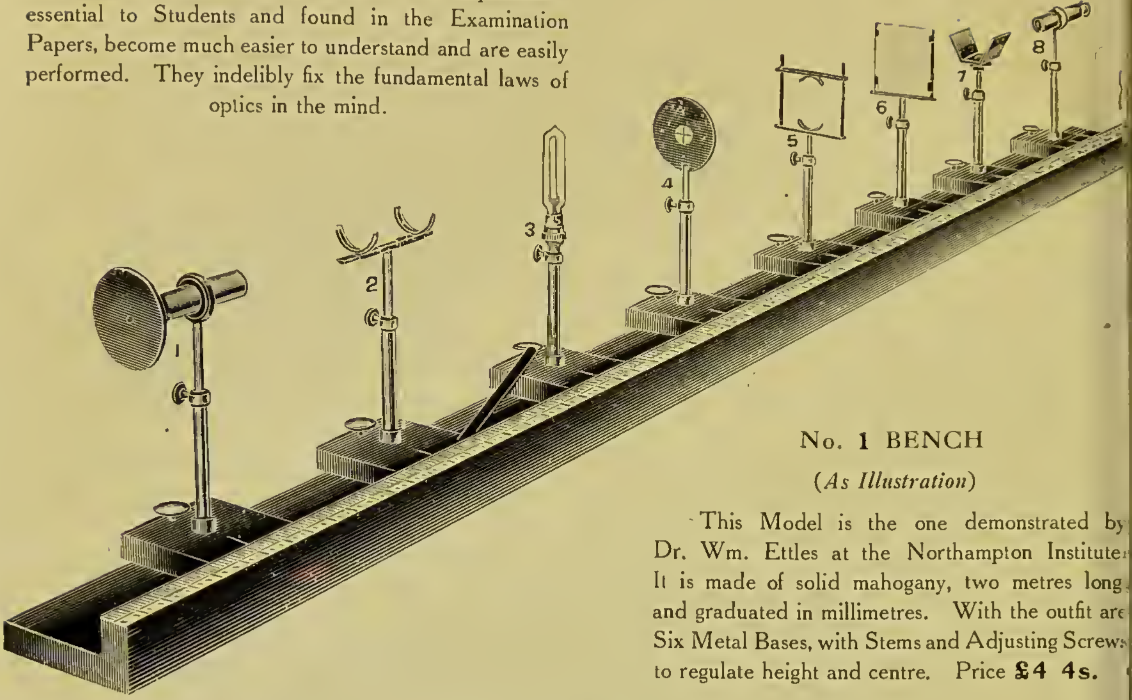

No. 1 BENCH

(As Illustration)

This Model is the one demonstrated by Dr. Wm. Ettles at the Northampton Institute. It is made of solid mahogany, two metres long, and graduated in millimetres. With the outfit are Six Metal Bases, with Stems and Adjusting Screws to regulate height and centre. Price **£4 4s.**

No. 2 BENCH.

A cheaper but thoroughly serviceable Bench, one metre long, and graduated in millimetres. The Bench and Stands are made of Solid Walnut, with Brass Stems, adjustable for height. There are six Bases and the necessary Accessories to form the complete outfit as given below. Price **£1 15s.**

No. 1 BENCH has the following Outfit :

6 Metal Bases

1—Collimator, with Achromatic Object Glass
2—Double Lens Holder
3—Lamp Holder
4—Screen with Cross Wires
5—Universal Lens Holder
6—Focussing Screen
7—Nodal Point Fitting
8—Telescope with Cross Wires, and Achromatic Object Glass and Huyghenian Eyepiece.
9—Standard Rod

No. 2 BENCH has the following Outfit :

6 Wooden Bases

1—Single Lens Holder
2—Two Supplementary Lens Clip Holders for 1-eye Spectacle Lenses
3—Glass Screen
4—Nodal Point Fitting
5—Telescope (Galileon)
6—Double Lens Holder
7—Cross Wire Screen
8—Collimator with Single Lens
9—Standard Rod
10—Plane Mirror

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